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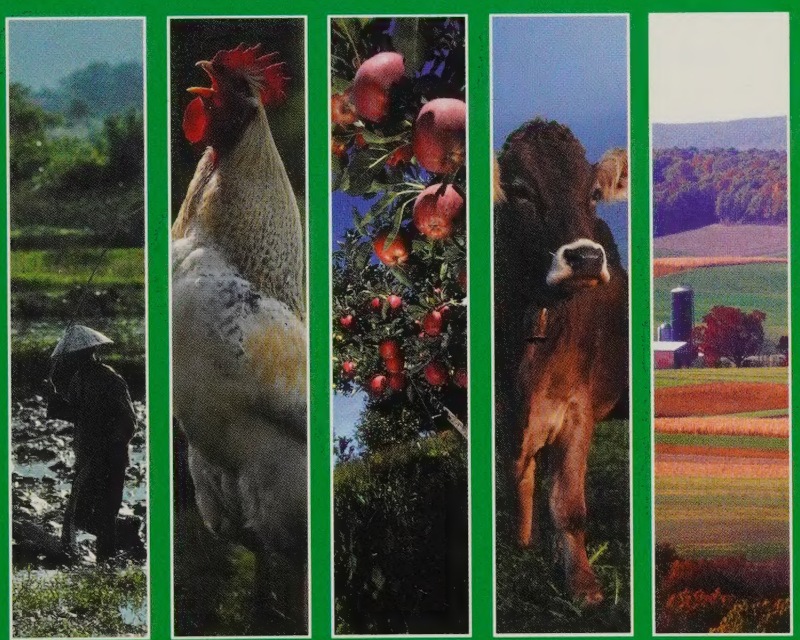

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# AMERICAN JOURNAL OF ALTERNATIVE AGRICULTURE

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The *American Journal of Alternative Agriculture* provides an international forum for original research and review articles on the biological, physical, social science, and policy aspects of alternative agriculture and food systems, focusing on the effective use of renewable resources and biodiversity in agro-ecosystems. The journal particularly welcomes multidisciplinary, holistic, systems research that addresses the multiple challenge of economically meeting basic human needs for food, fiber, and energy while maintaining essential natural and environmental resources.


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# Production and processing of organically grown fiber nettle (Urtica dioica *L.*) and its potential use in the natural textile industry: A review

C.R. Vogl and A. Hartl

Abstract. *In Europe, the perennial stinging nettle was cultivated during the 19th century until the Second World War and has a long history as a fiber plant. Clone varieties dating back to the early 20th century are still maintained at European research institutions. The fiber content of clones ranges from 1.2 to 16% dry matter, and fiber yields range from 0.14 to 1.28 Mg ha$^{-1}$. Varietal purity of fiber nettle can only be achieved by planting cuttings. The harvesting of fiber starts in the second year of growth and the crop may produce well for several years. Several agronomic practices influence fiber quality, but causal relations are not yet well understood. Various parts of the fiber nettle plant can be used as food, fodder and as raw material for different purposes in cosmetics, medicine, industry and biodynamic agriculture. Organically produced fibers are in demand by the green textile industry and show potential that is economically promising.*

Key words: fiber nettle, fiber production, fiber processing, natural textiles, organic farming, renewable resources

## Introduction

The perennial stinging nettle (*Urtica dioica* L.) is a common plant that grows on ruderal sites, in gardens, at the edges of forests and in wooded areas of riverine floodplains. Similar to flax (*Linum usitatissimum* L.) and hemp (*Cannabis sativa* L.), nettle fibers were used for the production of textiles in central Europe before the introduction of cotton (*Gossypium* sp.). The use of bast fibers from nettle stalks was documented by Nestorius in AD 900 (G. Edom, West Sussex, UK, personal communication, November 2001) and in the 12th century (Hegi, 1981). It is supposed that people used wild nettle plants growing near settlements for textile purposes. Nettle production in Europe began in the 19th century (Bredemann, 1959) and during the First and Second World Wars fiber nettle was promoted as a substitute for cotton. In the 1940s, about 500 ha of fiber nettles were cultivated in Germany and Austria and used for textile production (Bredemann, 1959; Grafe, 1928). However, processing facilities for nettle were destroyed during the Second World War and other cheaper fibers became more readily available (Waskow, 1995).

The authors' research interest in this plant is attributed to the following:

- Consumer awareness of toxic residues in textiles, its negative health impact and a need for alternatives to the conventional unsustainable textile chain.
- Public debate about socially unacceptable textile production and processing methods in Third World countries (e.g., cotton is criticized for the intensive input of pesticides and defoliants in conventional farming).
- Positive experiences and increasing demand for textiles made of organic cotton, flax and hemp.
- The search for plants that enable regional production and processing to avoid long-distance transport and to enable the closing of regional material flows.
- Interest in a 'new' fiber material that would increase the supply of organically grown domestic fibers in addition to flax and hemp.
- The possibility of transforming a common weed, such as nettle, into a commercial plant that could provide a wide range of products, by using not only stalks but also leaves, seeds and roots (multiple use of nettle organs).

Since the middle of the 1990s, the development of cultivation and processing methods for fiber nettle, and improved textile processing, has become a research topic in Germany, Austria and Finland. Companies, in cooperation with research institutions, are preparing for the market introduction of fiber nettle textiles. Two of the three projects reported in this paper focus on the development of production, processing and marketing strategies for organically grown fiber nettle (Table 1).

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**Table 1. Current and recently finished research projects on the market introduction of fiber nettle.**

| Title/Duration/Reference | Focus | Partners |
|---|---|---|
| From nettle to textile I + II (1997–2000, 2001–2003) [1] | Developing cultivation methods and fiber processing (biotechnological retting followed by mechanical fiber processing), production of yarns, production of knitted clothes, marketing of nettle clothes | Agricultural Research Centre of Finland (Ecological Research Station at Mikkeli and Research Station at Ruukki); FinFlax Ltd.; Kalajokilaakso Vocational College/ Crafts and Design Department (all Finland) |
| Nettle—reintroduction of stinging nettle cultivation as a sustainable raw material for the production of fibers and cellulose; FAIR-ST–8356 and FAIR-CT98–9615 (1999–2001) [2] | Developing cultivation methods in organic farming and cultivation of 2 ha of fiber nettles, testing of different fiber processing methods, testing of spinning and weaving, manufacturing of clothes and other textiles | Paptex GmbH, Fein-Elast Umwindewerk GmbH, Manfred Ghesla GmbH and Institute of Agrobiotechnology (Austria), Ertex GmbH, Stoffkontor and Institute of Applied Research Reutlingen (Germany), Zucchi S.p.A. (Italy), Heinrich Rimml and Textilpflege Bruno Widmer (Switzerland) |
| Natural textiles made of nettle—innovative technology and product development for the textile industry (1999–2002) [3] | Producing nettle clothes from cultivation to manufacturing. Developing cultivation methods in organic farming | Institute of Plant Production and Breeding, University of Göttingen; Thüringisches Institut für Textil- und Kunststofforschung e.V.; Institute of Applied Botany, University of Hamburg; Spremberger Tuche GmbH; Langhein-Textil GbR (all Germany) |

[1] L. Hakkarainen, Nivala, Finland (personal communication, May 2002).
[2] Web site: www.nf-2000.org/secure/Fair/S905.htm (viewed May 8, 2002) and www.ifa-tulln.ac.at/BPNEU/Homepage/Deutsch/BPdeFAN.htm (viewed May 6, 2002).
[3] Web site: www.gwdg.de/~mlehne/ab260301/OELB/nesselinfo.htm (viewed May 6, 2002).

## Methods

Information on fiber nettle was obtained from different sources, including the scientific literature and databases; interviews with groups involved in the agricultural and textile production of flax, hemp and nettle; a survey of Austrian natural textile producers and traders; and a 3-year scientific field trial using five clone varieties of organically grown fiber nettle (Hartl and Vogl, 2002). Information on the most recent agronomic and economic developments in the fiber nettle industry was accessed from Internet Web sites of public research institutions and private companies, and through e-mail and personal communication.

Data on nettle production are based on the results of field trials and large-scale farming operations conducted from 1920 to 1950 (Bredemann, 1959). Recent experience (Albrecht et al., 1997; Dreyer and Dreyling, 1997; Dreyer et al., 1996; Francken-Welz et al., 1999; Hartl and Vogl, 2002; Köhler et al., 1999; Lehne et al., 1998, 2001; Ruckenbauer et al., 2002; Schmidtke et al., 1998; TLL, 2001; Vetter et al., 1996; Wurl and Vetter, 1994) is limited to scientific field trials and pilot cultivation projects (e.g., 2 ha in Austria; S. Grabher, Dornbirn, Austria, personal communication, May 2002). Large-scale efforts to produce fiber nettle under current farming and cropping systems lack agronomic data. This paper summarizes the available data which should help scientists and practitioners to establish best management practices for the agronomic and economic production of fiber nettle by organic methods.

## Clone Varieties And The Availability of Fiber Nettle Plants

Stinging nettle (*Urtica dioica* L.) is a common plant that grows throughout the temperate regions of the Europe, Asia and North America (Hegi, 1981). It is highly variable in morphological characteristics and probably represents a number of subspecies (Bassett et al., 1974, 1977; Hegi, 1981; Tutin et al., 1964).

Fiber nettle is a cultivated form of wild nettle, the fiber content of which was increased by breeding, from about 5% in wild nettle plants (stalk dry matter) up to 17% in fiber nettles (Bredemann, 1959). For more than 30 years Bredemann evaluated the agronomic behavior and morphological characteristics of 170 provenances of wild nettle, selecting the most desirable ones for crossbreeding. Among the traits that Bredemann (1959) sought to maximize in his breeding program were:

- frost tolerance (provenances that sprout late and are less susceptible to late frost than those that sprout early);
- optimum growth (long, straight, stable and unbranched stalks, abundance of leaves and strong tillering); and
- high fiber content.

Clone varieties from the time of Bredemann are still maintained at the following research institutions:

- Institute of Applied Botany, University of Hamburg, Germany (Dreyer and Dreyling, 1997; Dreyer et al., 1996);
- Thüringer Landesanstalt für Landwirtschaft, Dornburg, Germany (Albrecht et al., 1997; TLL, 2001; Vetter et al., 1996; Wurl and Vetter, 1994);

Table 2. Range of fiber content (% of stalk dry matter) of fiber nettle (literature overview).

| Fiber content | Processing and analyzing methods | Material | Literature cited |
|---|---|---|---|
| 1.8–12.7 % | Chemical extraction with lye | 27 clone varieties dating to Bredemann (1959) | Dreyer et al. (1996), Dreyer and Dreyling (1997) |
| 1.2–12.7 % | Chemical processing method | Six clone varieties dating to Bredemann (1959) | Bredemann (1959), Dreyer et al. (1996) |
| 5.5–9.0 % | Chemical processing method | One clone variety dating to Bredemann (1959) | Bredemann (1959), Köhler et al. (1999) |
| 7.4–14.5 % | Chemical processing method | Three clone varieties dating to Bredemann (1959) | Bredemann (1959), Schmidtke et al. (1998) |
| 12.6–15.4 % | Adapted method of Heyland et al. (1995) | Two clone varieties 'Dornburg 1' and 'Dornburg 5' | Francken-Welz et al. (1999) |
| 8.1–16.0 % | Mechanical processing (decortication, opening) and succeeding chemical processing (alkali boil-off) | Five clone varieties dating to Bredemann (1959) | Hartl and Vogl (2002) |

- University of Göttingen, Germany (Köhler et al., 1999; Lehne et al., 1998; Schmidtke et al., 1998);
- University of Bonn (Francken-Welz et al., 1999); and
- University of Agricultural Sciences Vienna (Hartl and Vogl, 2002).

In this paper, the term 'clone varieties' is used to designate genetically identical nettle plants, obtained by vegetative propagation. However, these clones are not officially registered varieties. Nevertheless, according to some researchers (Table 2), these clone varieties do not attain the high fiber content of 17% stalk dry matter as reported by Bredemann (1959).

No fiber nettle varieties are officially registered in Europe. A description and differentiation of clone varieties dating back to Bredemann was published by Dreyer et al. (1996), and can be used for differentiating varieties using the UPOV criteria (UPOV, 1979).

## Agronomic Management of Fiber Nettle

### Soil

The requirements of fiber nettle cultivation are presumed to be similar to those for wild-growing stinging nettle. Fiber nettle requires fertile soils with a high organic matter content, which are rich in nutrients (especially N) and provide adequate water. Poorly drained and acid soils should be avoided. Histosols are especially suited for cultivation of fiber nettle (Bomme, 1988, 1990; Bredemann, 1959; Heeger, 1956; Langerfeldt, 1975; Olsen, 1921; Schmid, 1985; all cited in Weiß, 1994).

### Climate

Fiber nettle requires frequent application of water. The most ideal condition is when precipitation (or irrigation) is distributed uniformly over the main growing period. Fiber nettle is sensitive to desiccating winds (Bredemann, 1959). No precise data on consumptive water use and temperature limitations are reported in the literature to describe optimum site conditions for nettle.

### Sowing and planting

Seeds of fiber nettle can be drilled as a method of sowing, but the high degree of heterozygosity of the parents leads to a heterogeneous $F_1$. In a field trial, the maturity status of sown nettle plants differed by up to 4 weeks between single plants, which would make it difficult to specify the ideal harvesting date in commercial nettle cultivation. Sowing also leads to a reduction of fiber content: the fiber content of sown nettle plants was up to 2% lower than the fiber content of the mother plant which was cultivated under the same conditions and harvested at the same time (Vetter et al., 1996).

Varietal purity and a homogeneous crop of fiber nettle can only be achieved by vegetative propagation and planting of cuttings (e.g., top cuttings). These cuttings must be grown in greenhouses so that they develop roots before transplanting to fields (Bredemann, 1959; Dreyer and Dreyling, 1997; Vetter et al., 1996). Narrow spacing of young plants [50 cm × 50 cm, i.e., in rows 50 cm wide and 50 cm spacing between plants within a row (TLL, 2001; Vetter et al., 1996); 75 cm × 50 cm (Ruckenbauer et al., 2002)] as well as wide row spacing (rows 100–150 cm wide with different spacings within a row) are recommended (Dreyer and Dreyling, 1997; Hartl and Vogl, 2002; Köhler et al., 1999; Lehne et al., 2001; Schmidkte et al., 1998). The young plants can be transplanted by hand or with a machine designed for the purpose of planting horticultural crops.

Fiber nettles can be planted in April (Dreyer and Dreyling, 1997) and May (Bredemann, 1959; Francken-Welz et al., 1999; Hartl and Vogl, 2002; Köhler et al., 1999; Schmidkte et al., 1998). The required soil preparation

before planting is similar to methods used for the cultivation of herbs or vegetables (TLL, 2001).

## Crop rotations with fiber nettle

There is no recent research documenting the optimum sequencing of fiber nettle with other crops in a rotation sequence. In older literature, root crops and hemp are recommended for preceding fiber nettle because they are effective in suppressing weeds (Bredemann, 1959). Lupin (*Lupinus* sp.), and other legumes are also recommended for their nitrogen-fixing capacity (Bredemann, 1959). From an organic farming perspective, legumes are especially preferred as a preceding crop because of nitrogen fixation.

Possibilities for crops succeeding nettle are potatoes (*Solanum tuberosum* L.), sugar beet (*Beta vulgaris* L.) and other root crops. Rotating out of nettle fields requires intensive soil tillage (plowing in autumn or early spring, crosswise grubbing and harrowing twice) (Bredemann, 1959). Organic farmers could possibly sow a catch crop and plow in the winter to avoid loss of N from leaching. No data are available on problems in succeeding crops caused by nettle regrowth.

## Fertilization

Because nettle is a perennial crop that produces comparatively large amounts of biomass each year, it is important to focus research on ways of supplying nutrients, particularly N, in the case of organic farming. In recent research projects, both extensive [low application rates of mineral N fertilizers (Dreyer and Dreyling, 1997) or without mineral N fertilizers (Köhler et al., 1999; Schmidtke et al., 1998)] and intensive fertilization methods have been developed. The extensive methods include testing of undersown legume and grass species (Dreyer and Dreyling, 1997; Köhler et al., 1999; Schmidtke et al., 1998). On the other hand, under intensive cultivation, some researchers (e.g., Vetter et al., 1996) used very high rates of chemical N fertilizer (i.e., 160–240 kg N $ha^{-1}$) and close plant spacing (50 cm × 50 cm). The extremely high rates of chemical N fertilizer recommended for fiber nettle by Wurl and Vetter (1994) (i.e., 250–300 kg N $ha^{-1}$ $yr^{-1}$ as $CaNO_3$, and also see the recommendations of TLL, 2001) is neither allowed in organic farming, nor is it acceptable for environmental reasons.

Results of a field trial by Köhler et al. (1999) show that with undersown grass–clover mixtures (*Trifolium repens* and *Lolium perenne,* as well as 17 species of grasses and herbs, mulched or rotavated), stalk and fiber yields were reduced from the third production year on, and grass species of the underseed and weed growth increased. The negative effect of competition by the undersown species on the nettle yield was greater than the expected beneficial effect from legume nitrogen fixation. At low soil N levels (i.e., less than 20 kg N $ha^{-1}$), especially in the fourth crop, growth increases occurred mainly in the monocotyledonous species of the undersown plants and weeds. At the same time available N was increasingly immobilized in organic matter.

Köhler et al. (1999) concluded that the following conditions are essential for successful integration of undersown legumes and grasses in fiber nettle:

- wide row spacing of 150 cm;
- repeated inter-row soil cultivation before crop covering in the spring;
- reduced underseed growth from mid August to the end of April; and
- use of fast-growing legume species, e.g., common vetch (*Vicia sativa*) and crimson clover (*Trifolium incarnatum*).

To avoid competition with fiber nettles for water and nutrients, biannual and perennial grass species should not be used (Köhler et al., 1999).

Positive results were obtained in organic farming with undersown white clover (*Trifolium repens*) and application of slurry manure. An Austrian field trial with five fiber nettle clone varieties demonstrated high yields for the third crop year, and the authors concluded that there is high potential for improving the organic production of fiber nettle by supplying N through legume nitrogen fixation and manure slurry or barnyard (stable) manure (Hartl and Vogl, 2002, Table 3). The importance of good soil conditions was substantiated by Ruckenbauer et al. (2002), who reported stalk dry matter yields ranging from 1 to 10 Mg $ha^{-1}$ in experimental plots under varying soil conditions.

Further research on management practices to provide adequate nutrients for the organic production of fiber nettles was conducted at the Institute of Plant Production and Breeding at the University of Göttingen, Germany. Three manuring systems were tested: (1) underseeding of *Trifolium incarnatum* + stonemeal; (2) applying compost; and (3) applying cattle slurry and manure. The highest yields were achieved with cattle slurry and manure (4.4 Mg $ha^{-1}$ in 1999, and 3.2 Mg $ha^{-1}$ in 2000) (Lehne et al., 2001; see also Table 3).

## Weed management

Weed control is highly essential in the production of fiber nettle, especially in the first crop year. With organic farming, where methods of direct weed control are limited, preventive measures are important. Weed management begins with the selection of an appropriate preceding crop and with frequent harrowing of the seedbed. After crop cover is established, the primary weed problems are grasses. Narrow plant spacing (50 cm × 50 cm) promotes early establishment of crop cover for suppression of weeds, and is recommended with intensive cultivation (TLL, 2001; Vetter et al., 1996). Wide row spacing (100–150 cm, with or without legume underseeding) allows inter-row soil cultivation and is recommended for extensive production methods (Dreyer and Dreyling, 1997; Köhler et al., 1999; Schmidkte et al., 1998).

**Table 3. Range of stalk dry matter and fiber yields of fiber nettle for different methods of agronomic management.**

| Stalk dry matter (Mg ha$^{-1}$) | Fiber (Mg ha$^{-1}$) | Agronomic management | Literature cited |
|---|---|---|---|
| 4.4–7.3 | – | Fertilization with calcium ammonium nitrate: 200 kg N ha$^{-1}$ in spring and 100 kg N ha$^{-1}$ after the first cutting in autumn (including mineral nitrate in the soil). Plant spacing 50 cm × 50 cm | Vetter et al. (1996) |
| 4.88–11.52 | 0.14–1.28 | 20 Mg ha$^{-1}$ stable manure at the beginning, row spacing 100 cm, spacing within the row 50 cm | Dreyer et al. (1996) |
| 2.19–4.93 | 0.30–0.60 | 2.86 plants per m$^2$, row spacing 70 cm, one mechanical weed control in the second cultivation year (rotavating between the rows), no mineral fertilizers used | Schmidtke et al. (1998) |
| 2.66–5.52 | 0.21–0.49 | 2.86 plants per m$^2$, no mineral fertilizers used | Schmidtke et al. (1998), Köhler et al. (1999) |
| 6.71–8.12 | 1.09–1.22 | Three different plant spacings tested: 1.7, 2.5 and 5.0 plants per m$^2$, no information on fertilization and other cultivation methods | Francken-Welz et al. (1999) |
| 1.7–4.4 | 0.53 (max.) | Cultivation under conditions of organic farming. Row distance 150 cm, 2.86 plants per m$^2$, planting in 1997, testing of three manuring systems in the years 1999–2000: (1) underseed of *Trifolium incarnatum* + stonemeal; (2) compost; (3) manuring with cattle slurry and cattle manure | Lehne et al. (2001) |
| 2.3–9.7 | 0.3–1.02 | Cultivation under the conditions of organic farming. Plant spacing 100 cm × 50 cm, undersown with white clover (*Trifolium repens*), manuring with cattle slurry (total 150 kg N ha$^{-1}$ in three production years) | Hartl and Vogl (2002) |
| 1–10 (average 3.4) | – | Cultivation under conditions of organic farming. Planting distance 75 × 50 cm, organic fertilizers | Ruckenbauer et al. (2002) |

## Pest and disease problems

Fiber nettle is subject to a limited number of pest and disease problems (Amelung, 1995; Bredemann, 1959). For example, nettle is the host plant for many butterfly species whose caterpillars feed on nettle leaves. The gregarious caterpillars of *Aglais urticae* L. and *Inachis io* Hübner are most notable, as they develop quickly and can cause complete defoliation. Growth retardation of nettle may occur, especially in the first crop year, but plants usually recover quickly. Other insects (*Vanessa atalanta* L., *Cynthia cardui* L., *Doralis urticaria* Kalt.) and diseases (*Peronospora debaryi* Salmon et Ware, *Pseudoperonospora urticae* Lib. Salmon et Ware) cause only small, local damage. The development of major pest infestations in large-scale cultivation of nettle has not been reported.

## Timing of harvest

Fiber production of nettle begins with the second crop and continues successively. In the first year, nettle stalks do not achieve the quality required for fiber processing, i.e., the stalks are too thin, too ramified (branched) and have too many leaves (Bredemann, 1959). In the second year, fiber nettle can be harvested between mid July and early August (Vetter et al., 1996), or from early until late August (Bredemann, 1959).

Plants are ready for harvest when seed matures in the lower parts of the flowers of female clones (Bredemann, 1959). However, in a trial with different harvest dates, Vetter et al. (1996) showed that fiber nettle still blossoms at the plant apex when the highest stalk yield is reached. Vetter suggests harvesting when the stalks are equivalent to of 80% of the above-ground biomass. Thus, the harvest should begin before development of secondary lateral shoots from the nettle leaf axils. Lateral shoots do not cause a loss in fiber quality but interfere with processing because the stalks dry too slowly in the fields (Bredemann, 1959).

## Equipment for harvest

Machines with cutter bars can be adapted for harvesting fiber nettle (Vetter et al., 1996); however, improved harvesting technology for nettle has not yet been developed. Because the height and morphological characteristics of nettle stalks are similar to those of hemp, one can assume that the same harvesting machine could be used for either crop. However, problems, such as the wrapping of fibers around axles of rotating pieces of equipment and break-

down, will occur if the machines are not adapted to the harvest of fiber crops (Vogl and Hess, 1995).

### Yields

In the older literature, average stalk dry matter yields for fiber nettle range from 3 to 4 Mg $ha^{-1}$ (maximum 8 Mg $ha^{-1}$) (Bredemann, 1959). In recent research projects, however, both lower and higher yields were obtained (Table 3). In the authors' experiments, stalk dry matter yield of five nettle clone varieties ranged from 2.3 to 4.7 Mg $ha^{-1}$ in the second crop year (Hartl and Vogl, 2002). The dry matter yields of that year correspond to those obtained under extensive cultivation (without N fertilizer) (Schmidke et al., 1998). However, in the third crop year dry matter yields ranged from 5.6 to 9.7 Mg $ha^{-1}$, more than twice those of the second year (Hartl and Vogl, 2002). The large increase in yield was due to increased height (20–40 cm higher) and growth of runners, i.e., the number of stalks per plot more than doubled in the third crop year. Moreover, the undersowing of clover (*Trifolium repens*) likely had a positive effect on fiber nettle growth (Hartl and Vogl, 2002). Yields were even higher than those from the intensive cultivation system with 300 kg N $ha^{-1}$ $yr^{-1}$ (Vetter et al., 1996).

### Duration of nettle crops

According to Bredemann (1959), a fiber nettle crop can produce economical yields for 4 years. If grown longer, weed infestations tend to increase and yields decline. Reports that nettle can be grown for 10–15 years, or even without limit (Bouché and Grothe, 1877, 1884; Schürhoff, 1916; Wiesner, 1927; Zillig, 1918), have little basis (Bredemann, 1959). However, Vetter et al. (1996) indicated that cultivation for more than 4 years may be possible. According to these workers, the short cultivation period reported by Bredemann (1959) is likely due to the weakening of plants caused by the intensive soil cultivation necessary for controlling weeds in the wide plant spacing. Vetter et al. (1996) report that weed control is less critical with closer plant spacing and intensive N fertilization. Undisturbed growth allows a longer production period and a more useful life than that reported by Bredemann (1959).

## Processing

### Retting

At harvest, hemp is cut, then the stalks remain in the field for several days, during which time microbial enzymes break down the adhesive substance that binds the fibers and woody cores (also called shives) together, thereby allowing easy separation of both. The process is known as retting, and it works best when harvested stalks are exposed to alternate periods of high humidity and dryness, which enhances enzymatic activity with minimal stalk decomposition. Excessive rainfall after harvest can cause overretting, often resulting in stalk decomposition by microorganisms, reduced fiber yield and poor fiber quality. Retting studies with fiber nettle have shown that nettle stalks are prone to overretting, separation of fiber from shives is not easily achieved and fiber quality is often impaired (Bredemann, 1959).

### Processing methods

At present, acceptable methods and technology for large-scale processing of fiber nettle do not exist. However, a recent survey of processing methods for flax and hemp fiber suggest that some might be adapted for processing fiber nettle (Hartl and Vogl, 2000a). These include the following.

**Mechanical processing methods.** These have been developed by companies such as Bahmer (J. Bahmer, Söhnstetten, Germany, personal communication, August 1998), Temafa, and Charle & Co. (F. Charle, Bissegem-Kortrijk, Belgium, personal communication, September 1998; M. Wolpers, Bergisch Gladbach, Germany, personal communication, August 1998). However, fibers processed in this way cannot be used for textiles but only for alternative purposes.

**Physico-chemical processing methods.** These include: (1) the cottonizing method, i.e., equalizing fiber length through a special physical and chemical treatment developed by Flasin Faser GmbH (H. Costard, Neu Wulmsdorf, Germany, personal communication, August 1998); and (2) the steam explosion fiber processing method, developed by the Institute for Applied Research of Reutlingen University (K. Nebel, Reutlingen, Germany, personal communication, November 1998). Decorticated nettle fibers must be used in these methods. Fibers processed by the cottonizing or steam explosion method can also be used for textiles (garments).

**Microbiological–enzymatic processing methods.** These methods appear to be promising alternatives to physical or chemical processing. The waste-water is biodegradable and therefore poses no special disposal problems. Green and field-retted material can be used. Research on this process is being conducted at FIBRE, Bremen and Institute of Applied Botany, University of Hamburg, Hamburg, Germany (Dreyer and Müssig, 2000).

## Fiber Content, Fiber Yield and Factors Influencing Both

The fiber content of available nettle clone varieties contains a maximum of 16% of stalk dry matter (Table 2). To achieve a high fiber content and fiber yield the following factors must be considered.

### Clone variety

The fiber content at the time of maturity is an important clone characteristic (Dreyer et al., 1996; Schmidtke et al., 1998). Fiber content is influenced mainly by genotype and

little by the cultivation method and environmental conditions (year, plant spacing, underseeding). This is partially contradictory to the results of Bredemann (1959), who concluded that the fiber content varies considerably with weather conditions (dry weather has a negative influence) and nutrient supply.

### Plant density

Fiber yield reportedly increases with plant density (Francken-Welz et al., 1999). However, the effects of other fiber-quality parameters (fiber fineness, fiber strength, fiber elongation and length) were not tested.

### Harvesting date and cutting

When harvested late, the nettle stalks sprout small lateral shoots, which do not influence fiber quality but slow the drying rate of nettle stalks in the field, thereby delaying the processing operation. Late harvesting does not affect fiber consistency, and nettle fibers do not lignify. Leaving fiber nettle stalks in the field after maturity causes loss of quality because retting also destroys a part of the fiber. If the nettle is harvested prematurely, the fibers are not completely developed and are overly thin, thus reducing fiber quality.

Fiber can be harvested only once per year. Stalk regrowth in late summer and autumn after harvest is too short, too thin and too branched to provide good fiber quality. For the same reason, harvest of the first year's growth cannot be used for fiber processing (Bredemann, 1959).

### Part of the stalks

The upper part of the nettle stalk has a higher percentage of fibers and a lower percentage of woody core than does the lower part. One way to avoid this 'fiber heterogeneity' is to divide the stalk into two parts, using the upper part for textile production and the lower part for alternative purposes, e.g., insulation material (K. Nebel, Reutlingen, Germany, personal communication, November 1998).

### Nitrogen fertilization

Some researchers have reported that high N fertilization of flax has a negative effect on fiber quality (Dambroth and Seehuber, 1988). The effect of optimum N fertilization and management on fiber nettle yield and quality is unknown and further research is recommended (Vetter et al., 1996).

### Processing methods

Processing methods, i.e., the kind and intensity of equipment used and the kind, quantity and duration of chemicals used, can affect the percentage of fiber recovered, as well as fiber quality and suitability for spinning (Bredemann, 1959; Hartl and Vogl, 2002).

## Fiber Nettle as a Raw Material for Natural Textiles

At present, fiber nettle textiles are not available on the market, as indicated by a survey of 15 Austrian natural textile producers and 27 natural textile traders (Hartl and Vogl, 2000a). Both groups were asked to estimate the potential market value for nettle in the textile industry. The responses did not provide a clear answer (one-third did not answer the question, one-third predicted positive opportunities, the remaining third were negative).

There are, however, companies working in cooperation with research institutions on the market introduction of fiber nettle textiles (Table 1). According to the German company Stoffkontor Kranz AG, the first nettle textiles produced on an industrial scale will be available in 2002. The first sample collections of nettle fabrics with the trade name Nettle World® have already been presented (Web site www.stoffkontor-ag.de, viewed May 8, 2002).

The Austrian natural textile company Paptex GmbH is now preparing to introduce fiber nettle textiles to the market. This work has been in progress since 1999 and was financed partially by two EU research projects. At present 2 ha of fiber nettle are cultivated organically in Austria. While the research project is now complete, the construction of an industrial-scale, economic processing line is planned as a next step. The tested fiber processing methods will provide yarn qualities of Nm 10 (nettle yarns) and Nm 20 (nettle/cotton yarns). Compared with other natural fibers, nettle fibers have especially suitable characteristics for use in bed-linen (e.g., moisture absorption) (S. Grabher, Dornbirn, Austria, personal communication, May 2002).

The test marketing of a sample collection of knitted nettle clothes by Finnish companies is expected at the end of this year. The clothes will be made with mixed yarns, i.e., 80% nettle, 20% silk; and 60% nettle and 40% viscose (L. Hakkarainen, Nivala, Finland, personal communication, May 2002).

## Possibilities for Multiple Uses of Fiber Nettle

Nettle can be used in various industries (Table 4). This multi-purpose strategy could help to promote fiber nettle as a newly emerging crop. However, it is unlikely that all of these uses could be fulfilled solely by the production of fiber nettle. Bredemann (1959) discussed how the various uses of fiber nettle might be achieved for 1 year's crop through sequential cutting and regrowth:

- first cutting at the end of April, used for fodder, medical drugs or for industrial purposes, such as chlorophyll production;
- second cutting at the end of June to be used for fiber production;
- third cutting in September (no further information given on the purpose).

**Table 4. Other potential uses of nettles.**

| Field of application | Use | Part of the plant | Literature cited |
|---|---|---|---|
| Medicine | Hemostatic, diuretic, anti-arthritic, anti-rheumatic anti-itch, anti-inflammatory | Dried leaves (tea) and juice made from fresh plants | Lutomsky and Speichert (1983), Monographie (1987), both cited in Dreyer et al. (1996) |
| Food | Spinach and soups[1] | Young plants and leaves | Dreyer (1995) |
| Cosmetics | Soaps, shampoos, hair lotion | No details given | Dreyer (1995) |
| Industrial use | Chlorophyll production[2] | Leaves and whole plants | Bredemann (1959) |
| Forage crop | Used fresh, dried, milled and silaged during periods of forage shortage before, during and after the First and Second World Wars; for feeding poultry, cattle, horses and pigs | Seeds, leaves, nettle shives, whole plant | Bredemann (1959) |
| Horticulture | Used in bio-dynamic agriculture (pest control and as a means to stimulate growth) | | Bredemann (1959), Dreyer (1995) |

[1] Bredemann (1959) mentions, in addition, carotene extract for vitamin A accumulation, margarine, tea, seeds (24.9–32.65% oil content), juice made of fresh plants. During the Second World War used as spinach replacement, cookies made of leaf flour, vegetable sausage, dumpling, soufflé and pie.

[2] Bredemann (1959) mentions, in addition, use of nettle for paper production and use of nettle roots as a dye (traditionally, used in Sweden for coloring Easter eggs).

However, Bredemann (1959) expressed some doubts as to the viability and practicality of such a cutting regime, because it could result in a loss of crop vigor and reduced fiber quality, due to the short growing period preceding the cutting and branched, thin stalks. Another possibility for multiple use could be harvest of the first year's crop that is not considered suitable for fiber production (Bredemann, 1959) (Table 4). From the second crop year on, nettle can be cut a second time in autumn for use of leaves, e.g., as medicine (Vetter et al., 1996) (Table 4). With respect to cultivation technique and economic concerns, it has yet to be shown how different uses can be combined in an efficient and effective manner.

Nettle fibers were also tested as a cost-effective and environmentally sound replacement for glass or carbon fibers, e.g., as composite in the automobile industry, and in the replacement of asbestos fibers (Vetter et al., 1996). Results of these tests have not been published. According to Lützkendorf et al. (1999), cited in Stadler (2000), some of the characteristics of nettle fibers are superior to those of flax.

## Summary and Conclusions

Research projects at the Universities of Hamburg, Göttingen, Bonn, the University for Agricultural Sciences Vienna and the Thüringer Landesanstalt für Landwirtschaft, Dornburg provide valuable information on the cultivation of fiber nettle, using both conventional and organic farming methods. Currently, there is no commercial production of fiber nettle and consequently nettle textiles are not available from the inventories of major natural textile producers and traders. The market introduction of nettle textiles is now planned by natural textile companies in Germany, Austria and Finland.

Opportunities for successful organic cultivation and processing of fiber nettle lie in (1) the trend towards goods produced in an environmentally sound way; (2) the increase in the range of domestic raw fiber materials, in addition to flax and hemp, in temperate climates; (3) the high quality expected of fibers; (4) the suitability for fiber cultivation in an environmentally sound way (few pests and diseases, soil protection due to perennial cultivation, less intense weed control as soon as crop cover develops).

One may presume that the cultivation, processing and marketing of fiber nettle would be somewhat similar to those of flax and hemp. To lessen the impact of volatile market prices, close cooperation between farmers, fiber processing companies, and spinning and weaving companies is needed to enhance added value. Moreover, to increase contribution margins and ensure a broader marketing base, a multi-purpose use of fiber nettle and the development of a wide range of products should be principal goals. Applications in the food, cosmetics, medical and drug industries should provide special opportunities for organic production.

Cultivation methods for fiber nettle (especially cutting regimes) and cooperation systems should be developed to combine the present applications of common nettle with fiber production. Due to the perennial cropping of fiber nettle, and due to the fact that nettle can be used for fiber production from the second cultivation year on, cooperation between farmers and processing companies should ensure demand for a longer period of time.

At present, the limiting factors for fiber nettle production are the lack of (1) suitable harvesting technology; (2) large-scale fiber processing; and (3) large-scale textile proces-

sing. The possibility of processing fiber nettle at existing flax and hemp industrial plants should be assessed. The economic factors involved in the cultivation and processing of fiber nettle need to be evaluated thoroughly.

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# In-row residue management effects on seed-zone temperature, moisture and early growth of barley and canola in a cold semi-arid region in northwestern Canada

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Abstract. *Spring crop growth is often influenced by water stress and lower soil temperature in the northern Canadian prairies. Tillage system effects on soil temperature, moisture and establishment of barley and canola in silt loam and sandy loam soils in northern British Columbia were investigated in 1992 and 1993. The tillage systems were: no-tillage (NT), modified no-tillage where surface residue was pushed aside from a 7.5 cm zone above the planting rows (MNT), and conventional tillage (CT). The MNT and CT had higher weekly maximum and weekly mean seed zone temperatures than NT. Mean weekly maximum seed-zone soil temperature was 1.6°C lower in MNT and 3.7°C lower in NT than in CT during the first 10 weeks after planting (WAP) in 1992. Compared to NT and MNT, barley in CT was slow to establish during the first three WAP in the silt loam in 1992 and 1993, and in the sandy loam in 1992, due to early water stress from low rainfall. Barley emergence was delayed by 6 days in NT and 11 days in CT in 1992 and by 3 days in NT and 7 days in CT in 1993 compared to MNT in the silt loam soil. Early in the growing season, barley growth was retarded more in the CT than NT and MNT at both sites. Canola growth was significantly improved in the MNT over that in the NT and CT in 1993. The MNT was more beneficial for crop establishment during prolonged dry periods than CT, and for emergence and growth compared with NT under extremely wet soil conditions.*

Key words: barley, canola, crop establishment, no-till, reduced tillage, soil temperature, soil moisture

## Introduction

In areas of the northwestern Canadian prairies, early crop growth and development can be adversely affected by inadequate soil warming and excessively dry or wet moisture conditions. Water availability and soil warming are the two main factors limiting plant growth in this semi-arid region. Many producers in the northern regions are reluctant to adopt no-tillage. Reasons frequently cited for not practicing no-till are cool spring soil temperature and excessive residue on the surface under this system resulting in slow soil warming, reduced germination and early plant establishment. This is critical in areas, like the Peace River region of Alberta and British Columbia, with a short growing season.

Soil moisture and temperature can be modified by altering the patterns of previous crop residue cover on the soil surface (Arshad and Azooz, 1996; Bristow, 1988). Residue management, such as creating a residue-free strip over the planting rows, can be used to minimize the negative impact of no-tillage on soil temperature while still allowing for improved soil moisture conditions (Frye, 1986; Kasper et al, 1990; Lindwall and Erbach, 1983; Shinners et al., 1994). Planting in residue-free areas has been found to increase soil temperature and improve corn (*Zea mays* L.) germination (Al-Darby and Lowery, 1987; Azooz et al., 1995; Fortin, 1993). However, few such studies have been conducted on crops with narrow spacings because of difficulties in creating residue-free planting rows (Arshad et al., 2002). Our study investigates the impact on crop growth of mechanically pushing aside the in-row residue, thus creating a 7.5 cm wide residue-free strip over the planting rows. The specific objective was to determine whether altering previous crop residue cover on soil surface under no-tillage system can modify soil moisture and temperature regimes sufficiently to improve seedling emergence and early crop establishment.

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## Materials and Methods

### Experimental sites

The study was conducted in 1992 and 1993 in field experiments at two sites that were initiated in 1979 on a Donnelly silt loam (fine-loamy, mixed, frigid Typic Cryoboralf) near Dawson Creek, British Columbia

(55°42′N, 120°21′W), and in 1988 on a Donnelly sandy loam (course-loamy, mixed, frigid Typic Cryoboralf) near Rolla, British Columbia (55°56′N, 120°10′W). The crops preceding these experiments were continuous barley (*Hordeum vulgare* L.) on the silt loam soil at Dawson Creek site (1979–1991), and barley in rotation with canola (*Brassica campestris* L.) on the sandy loam soil at Rolla site (1988–1991). Barley was grown at both sites in 1991. Annual precipitation in the study area was 303 mm in 1992 and 439 mm in 1993. The growing season (May–September) precipitation was 178 mm in 1992 and 322 mm in 1993. Mean 30-year (1962–1991) annual precipitation is 504 mm, with 289 mm occurring from May to September. The daily mean rainfall during the growing seasons at the two study sites is shown in Figure 1.

### Tillage treatments, experimental design and planting

Tillage treatments were:

- conventional tillage (CT)—one fall tillage to a 12–15 cm depth with a medium-duty cultivator having 25 cm wide sweeps and equipped with chisels, two spring operations with a medium-duty cultivator to a depth of 8–10 cm, and seeding with a double-disk press drill;
- no-tillage (NT)—direct seeding with a zero-till double-disk press drill with residue left on the soil surface; and
- modified no-tillage (MNT)—same as NT except surface residue was pushed aside by hand (our recent work now uses a locally made attachment to the drill; Arshad et al., 2002) from a 7.5 cm wide zone centered over the crop rows at planting.

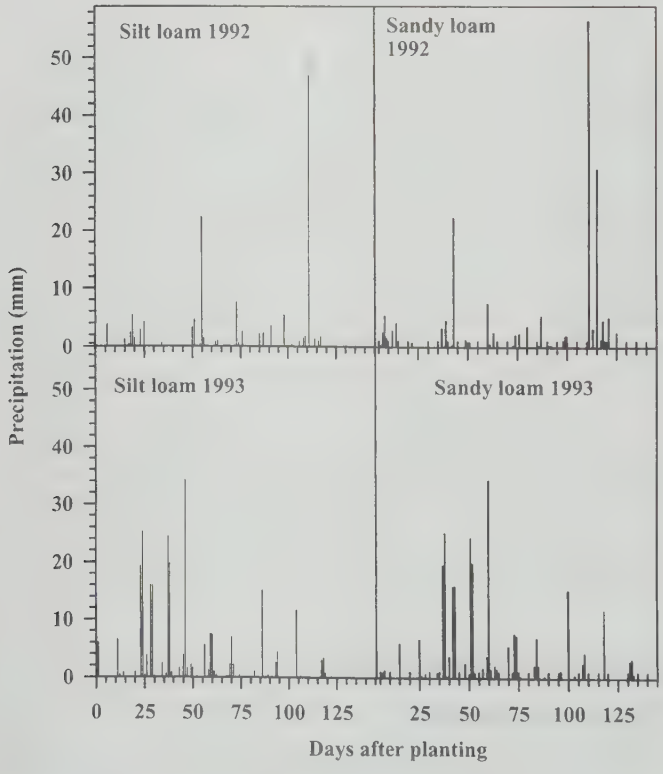


**Figure 1. Rainfall distribution pattern during the growing seasons in 1992 and 1993 at the Dawson Creek (silt loam) and Rolla (sandy loam) sites.**

The treatments were replicated four times in a randomized block design. Individual plots were 30 m long and 5 m wide with seed rows spaced 19 cm apart.

Barley was grown at the Dawson Creek site in both seasons (planted on May 15, 1992 and May 31, 1993). At Rolla, barley was grown in 1992 (planted May 27) and canola in 1993 (planted May 17). Planting depths were 2.54 cm for barley and 1.27 cm for canola under all tillage treatments.

### Soil moisture and temperature measurements

Volumetric soil moisture content was determined at least 11 times during May–August in 1992 and in 1993, at both sites, with time domain reflectometry (TDR) employing 15 cm waveguides. Measurements were made in the planting rows at 0–15 cm depths by taking two readings from each replicate treatment.

To determine water retention characteristics of soils under CT and NT systems, triplicate undisturbed soil cores were collected at 0–7.5 cm depth in planting rows in each of the four replicate treatments on June 25, 1992 and 1993 (41 and 25 days after planting in the silt loam soil at Dawson Creek site and 29 and 39 days after planting in the sandy loam soil at Rolla site, respectively) with an Uhland sampler (7.5 cm diameter). Soil cores were saturated in a shallow water bath for at least 4 days. The saturated cores were then subjected to stepwise decrease in matrix potential at –5, –20, –40, –60, –100 and –160 kPa, using a pressure plate extractor (Model 1250, Soil Moisture Equipment, Santa Barbara, CA). The matrix potential was maintained until outflows ceased. The outflows were recorded at different times at each matrix potential. After the final pressure step, the soil core was weighed and removed from the retaining cylinders for gravimetric water content and bulk density determination. The final water contents were computed from outflow volume at a given pressure and soil volume of each core.

Hourly soil temperature was recorded, using a CR7 datalogger, with 32-gauge copper-constantan thermocouples installed in planted rows at 0, 5, 10, 20 and 50 cm depths from 5 to 91 days after planting (May 19 to August 16) in 1992, and from 3 to 70 days after planting (June 2 to August 8) in 1993. These depths were selected to evaluate the effects of tillage and residue management on soil temperature in and below the tilled zone. Thermocouples were installed horizontally through pits, 7.5 cm wide × 20 cm long × 50 cm deep. Thermocouples were inserted 10 cm into the soil from the edge of the pits. After installing the thermocouples, the pits were packed carefully using the same layers of the soil. Soil temperature measurements were recorded in triplicate at randomly selected points in

each of the four replications. Soil temperature was recorded only in the silt loam soil at Dawson Creek site.

Daily soil growing degree days (SGDD) were calculated from the hourly measured soil temperature (°C) at the 0 and 5 cm depths, using the following relationship (Al-Darby and Lowery (1987):

$$\text{SGDD} = \sum_{j\ 1}^{N} \left[ \left( \sum_{i=1}^{i=24} \frac{T_i}{24} \right) - T_c \right]$$

and

$$T_i \frac{(T_0 + T_5)}{2}$$

where $T_i$ is the average seed zone temperature at the $i$th hour, $T_c$ is the critical temperature (5°C), $T_0$ is the soil surface temperature and $T_5$ is the soil temperature at 5 cm depth. The temperature below which no growth of barley takes place is 4.4°C (Nuttonson, 1957) and a general guide for critical temperature for cereal crops is 5.6°C (Carter, 1965). The base temperature for canola is 5°C (Kondra et al., 1983). Based on information in the foregoing reports, the critical temperature for this study was selected as 5°C.

### Residue cover and areal density measurements

Percent residue cover, from four randomly selected 1 $m^2$ areas per treatment, was determined 1 week after planting by using the line-transect method (Laflen et al., 1981). To determine residue areal density (crop residue mass/unit area), samples were collected from three randomly selected 1 $m^2$ areas and a subsample oven dried at 60°C. The oven-dry weight/unit area is the residue areal density.

### Plant emergence and crop growth

Two randomly selected 1 $m^2$ areas per plot (eight measurements for each treatment) were used for weekly dry matter measurement. Plant emergence was determined by counting the number of plants within randomly selected 2 m segments of eight rows in each plot (32 rows for each treatment). Percent of crop emergence was calculated based on the final plant population (i.e., number of plants at a given time divided by the final number of plant population multiplied by 100). Growth stages of barley on Feekes scale are described according to the guidelines outlined by McLelland (1982).

### Statistical analysis

Statistical analysis was performed using General Linear Models in SAS code (SAS Institute, 1990). Data were evaluated by analysis of variance for randomized complete-block design to detect significant differences among tillage treatments each year. Analysis of variance using a split plot in space and time separated the effects of day after planting and soil depth on soil moisture, temperature and crop data. When the $F$ test indicated significant differences at the 0.05 probability level ($P \leq 0.05$), means were separated by the least significant difference (LSD) method (Steel and Torrie, 1980).

## Results and Discussion

### Seed zone soil temperature

The presence (NT) and absence (MNT) of the residue on the soil surface above the seed zone, or incorporated residue in the tilled zone (CT), had a marked effect on seed zone soil temperature in both 1992 and 1993. Compared with NT, the CT and MNT treatments had a greater effect on the weekly maximum than on the weekly mean seed zone soil temperature during the first 10 weeks after planting (WAP) (Tables 1 and 2). The temperature differences were caused by differences in percent cover of previous crop residue (Table 3) and/or by the differences

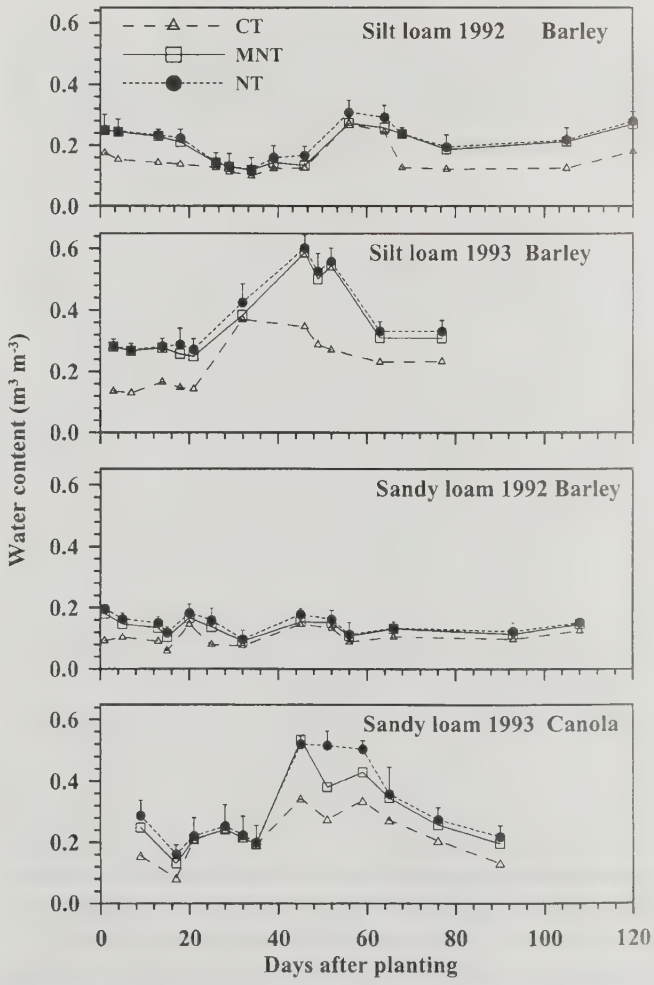


**Figure 2. Soil water content in the top 15 cm layer as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) at the Dawson Creek (silt loam) and Rolla (sandy loam) sites. The vertical bars represent the LSD at $P \leq 0.05$.**

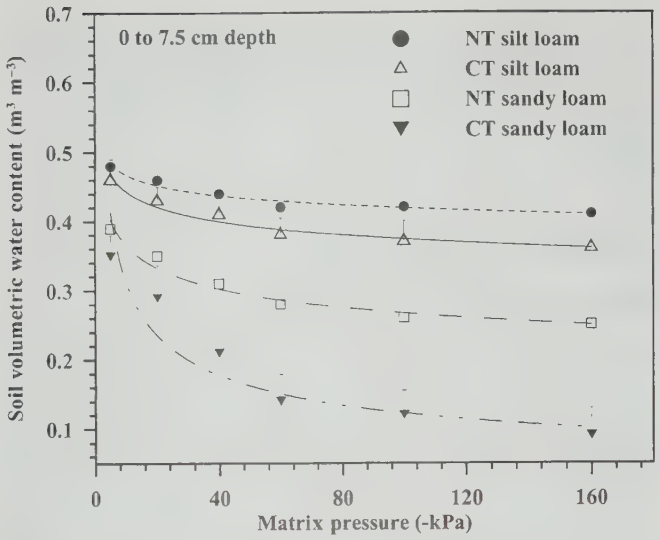


**Figure 3. Soil water retention as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) at the Dawson Creek (silt loam) and Rolla (sandy loam) sites. The vertical bars represent the LSD at $P \leq 0.05$.**

**Table 1. Weekly average seed zone maximum temperature (°C) in the silt loam soil at the Dawson Creek site as affected by no-tillage (NT), modified no-tillage (MNT) and conventional tillage (CT) treatments.**

| | 1992 | | | | 1993 | | | |
|---|---|---|---|---|---|---|---|---|
| WAP[1] | CT | MNT | NT | $LSD_{0.05}$ | CT | MNT | NT | $LSD_{0.05}$ |
| 1 | 16.7[2] | 15.1 | 13.5 | 1.4 | 22.2 | 20.7 | 18.9 | 1.0 |
| 2 | 18.0 | 16.1 | 14.1 | 1.3 | 21.8 | 20.4 | 18.8 | 0.7 |
| 3 | 19.8 | 17.7 | 15.6 | 1.0 | 21.4 | 20.6 | 19.0 | 1.3 |
| 4 | 18.6 | 16.9 | 15.2 | 1.7 | 21.9 | 20.9 | 19.0 | 1.3 |
| 5 | 23.9 | 21.3 | 19.3 | 1.0 | 19.8 | 19.4 | 17.9 | 1.5 |
| 6 | 27.2 | 25.1 | 23.1 | 2.1 | 20.1 | 19.1 | 18.1 | 1.5 |
| 7 | 27.6 | 26.0 | 23.4 | 1.7 | 19.4 | 19.2 | 18.6 | 1.7 |
| 8 | 27.0 | 25.4 | 23.0 | 2.0 | 22.7 | 22.0 | 20.8 | 1.1 |
| 9 | 24.0 | 23.1 | 20.4 | 2.7 | 21.5 | 20.9 | 19.8 | 1.3 |
| 10 | 23.6 | 22.7 | 20.9 | 1.7 | 20.0 | 19.5 | 18.3 | 2.1 |
| Mean | 22.6 | 21.0 | 18.9 | 1.7 | 21.1 | 20.3 | 18.9 | 1.4 |

[1] WAP, weeks after planting.
[2] Mean soil temperature over 0 and 5 cm depth. Note: soil temperature data were only obtained at the Dawson Creek site.

in soil moisture content and water retention (Figs. 2 and 3) among the treatments. Weekly maximum and mean seed zone soil temperature of the MNT were closer to those of CT than NT. The average daily maximum soil temperature over the first 10 WAP was 1.6°C lower in MNT and 3.7°C lower in NT than in CT in 1992 (Table 1), and the mean temperature was 0.7°C lower in MNT and 2.3°C lower in NT than in CT during 1992 (Table 2). The maximum and daily mean seed zone soil temperature in the CT and MNT treatments were significantly higher than in the NT treatment, but did not differ between themselves.

**Table 2. Weekly average seed zone temperature (°C ) in the silt loam soil at the Dawson Creek site as affected by no-tillage (NT), modified no-tillage (MNT) and conventional tillage (CT) treatments.**

| | 1992 | | | | 1993 | | | |
|---|---|---|---|---|---|---|---|---|
| WAP[1] | CT | MNT | NT | $LSD_{0.05}$ | CT | MNT | NT | $LSD_{0.05}$ |
| 1 | 12.0[2] | 11.7 | 10.6 | 1.1 | 16.4 | 16.2 | 15.0 | 0.54 |
| 2 | 13.5 | 12.1 | 10.7 | 1.3 | 16.2 | 15.6 | 15.1 | 0.41 |
| 3 | 15.1 | 14.4 | 12.4 | 0.5 | 16.6 | 16.4 | 15.4 | 0.53 |
| 4 | 15.6 | 14.7 | 13.0 | 0.5 | 16.6 | 16.5 | 15.5 | 0.64 |
| 5 | 17.7 | 16.8 | 14.9 | 0.7 | 15.7 | 15.4 | 14.5 | 0.56 |
| 6 | 19.4 | 18.1 | 16.2 | 0.7 | 14.9 | 14.8 | 14.1 | 0.58 |
| 7 | 21.0 | 20.8 | 19.1 | 1.2 | 16.2 | 15.8 | 15.2 | 0.62 |
| 8 | 19.1 | 18.8 | 17.8 | 0.9 | 17.6 | 16.9 | 16.3 | 0.57 |
| 9 | 19.3 | 18.4 | 17.6 | 1.4 | 18.2 | 17.5 | 16.8 | 0.64 |
| 10 | 21.4 | 20.7 | 19.1 | 1.2 | 15.1 | 14.3 | 13.6 | 0.59 |
| Mean | 17.4 | 16.7 | 15.1 | 1.1 | 16.4 | 16.0 | 15.1 | 0.59 |

[1] WAP = weeks after planting.
[2] Mean soil temperature over 0 and 5 cm depth.

Removal of the previous crop residue from the center of plant rows greatly influenced the seed zone soil temperature. The temperatures were above 16°C for over 49 and 82 hours in the MNT and CT treatments, respectively, during May 20–31, 1992, while the seed zone temperature in NT was mostly below this level during the same period (Fig. 4).

A similar pattern was observed during June 2–12, 1993. Removal of the previous crop residue from the planting rows in the MNT system resulted in increased soil temperatures in the seed zone as compared to the NT system.

## Seed zone soil moisture

The amount of water retained in soil at 0–7.5 cm depth was greater in NT than CT at both sites. Large differences in soil water retention occurred between –40 and –160 kPa (Fig. 3). Evidently a greater volume of water was stored in the NT than CT; the soil under long-term NT system had more capacity to retain water captured during rainfall events.

The 1992 and 1993 growing seasons at both sites were characterized by limited rainfall and low soil moisture in the top 15 cm soil layer during the early period of the growing season (Figs. 1 and 2) The rainfall received during the first three WAP was 14.6 mm in 1992 and 8.8 mm in 1993. The CT treatment had significantly lower moisture content than the NT and MNT treatments in early spring of both years. The increased soil moisture in NT and MNT treatments may be due to increased snow trapping and reduced evaporation losses because of greater quantities of surface residue in these plots as compared to CT plots (Table 3). There was a rapid loss of soil moisture from 0.25 to 0.12 $m^3 m^{-3}$ in NT and MNT, and from 0.18 to 0.10 $m^3 m^{-3}$ in CT in the top 0–15 cm layer in the silt

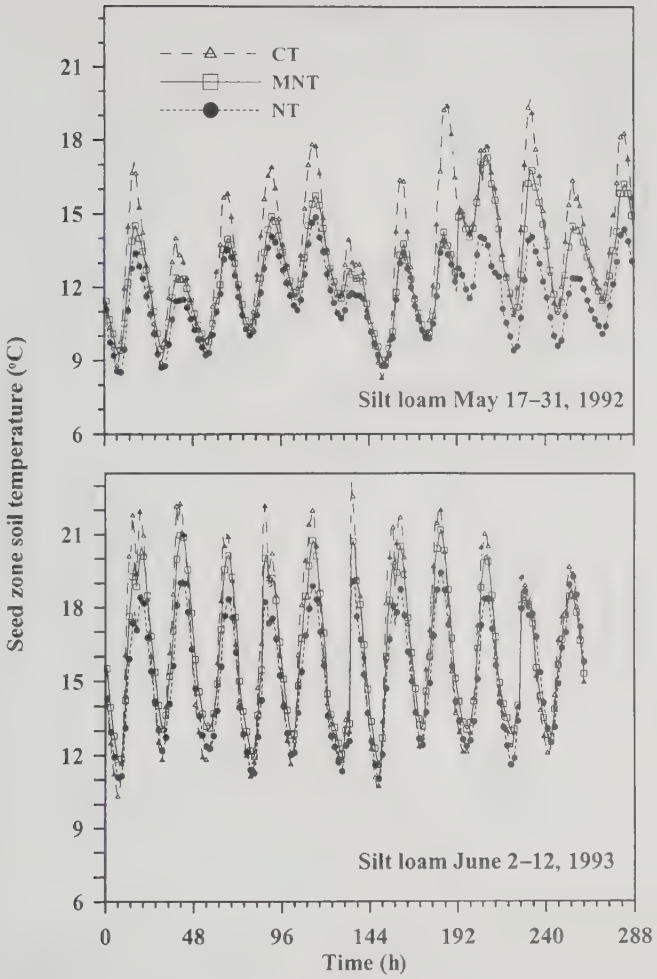


**Figure 4. Hourly soil temperature as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) in the silt loam soil at Dawson Creek for two different time periods.**

loam (Fig. 2) during the first drying period in 1992. However, the trend of significantly lower moisture content in CT compared with MNT and NT continued throughout the 1992 growing season despite several rainfall events (Fig. 1) that replenished soil moisture storage. The long-term continuous no-tillage system (NT and MNT) had a more stable soil structure, better pore continuity, hydraulic conductivity and infiltration rate than the CT, and resulted in higher moisture content and retention in NT than in CT (Arshad et al., 1999).

Several storms occurred during 24–56 days after planting (165.6 mm) at the silt loam soil site, and during 22–64 days after planting (209.9 mm) at the sandy loam soil site in 1993, and restored the soil moisture content at the end of growing season close to, or greater than, the level early in the 1992 growing season (Fig. 2). In spite of the higher moisture fluctuations during the wet period (Fig. 1) in 1993, the NT and MNT soils stored a higher proportion of precipitation, as compared to the CT soils, at both sites. In terms of soil moisture, the MNT treatment provided a soil environment closer to that of NT, being more favorable than CT. Reduced soil disturbance and in-row residue

**Table 3. Residue cover and areal density at one week after planting under no-tillage (NT), modified no-tillage (MNT) and conventional tillage (CT) treatments.**

| Treatment | Residue cover | | Residue areal density | |
|---|---|---|---|---|
| | 1992 | 1993 | 1992 | 1993 |
| | % | | Mg ha$^{-1}$ | |
| Silt loam at Dawson Creek site | | | | |
| NT | 73.8 | 75.2 | 6.7 | 6.1 |
| MNT | 59.8 | 60.2 | 5.9 | 6.0 |
| CT | 4.7 | 3.9 | 1.4 | 1.2 |
| $LSD_{0.05}$ | 9.8 | 11.1 | 1.3 | 0.7 |
| Sandy loam at Rolla site | | | | |
| NT | 69.4 | 60.2 | 4.9 | 5.1 |
| MNT | 58.3 | 61.6 | 4.3 | 4.5 |
| CT | 5.3 | 4.3 | 1.7 | 1.6 |
| $LSD_{0.05}$ | 11.1 | 8.4 | 1.2 | 0.9 |

removal in the MNT was beneficial for crop development during the prolonged period with little or no precipitation (Fig. 1) and resulted in higher temperature than in the NT (Tables 1 and 2).

## Barley and canola emergence

Relatively lower soil moisture in CT plots early in the growing season of 1992 and 1993 (Fig. 2) significantly influenced barley emergence at both sites (Fig. 5). The lower soil moisture content under all treatments during the early growing seasons in both years contributed to an increase in soil growing degree days (SGDD) required to obtain the final plant population in each of the treatments. About 3 weeks after planting, pronounced differences were observed in SGDD (Fig. 6) among the three tillage treatments. The lower barley plant population in CT compared with the NT and MNT treatments shows that early crop establishment depended not only on soil temperature but also on soil moisture in each treatment early in the drought period (Figs. 2–5). This effect was more obvious in the silt loam than the sandy loam soil. The barley emergence under MNT was improved by altering crop residue that increased seed zone soil moisture when compared to the CT system, and increased temperature when compared to the NT system (Tables 1, 2 and Fig. 2). Because of improved soil moisture and temperature there was a significant increase in barley emergence with in-row residue management in MNT.

The poor emergence (Fig. 5) of barley in CT plots during the first 3 weeks of both years in silt loam soil, compared to MNT and NT plots, was largely due to early water stress, as indicated by the rainfall and soil moisture data (Figs. 1 and 2). The more rapid plant emergence under the MNT treatment compared with the other two treatments in both

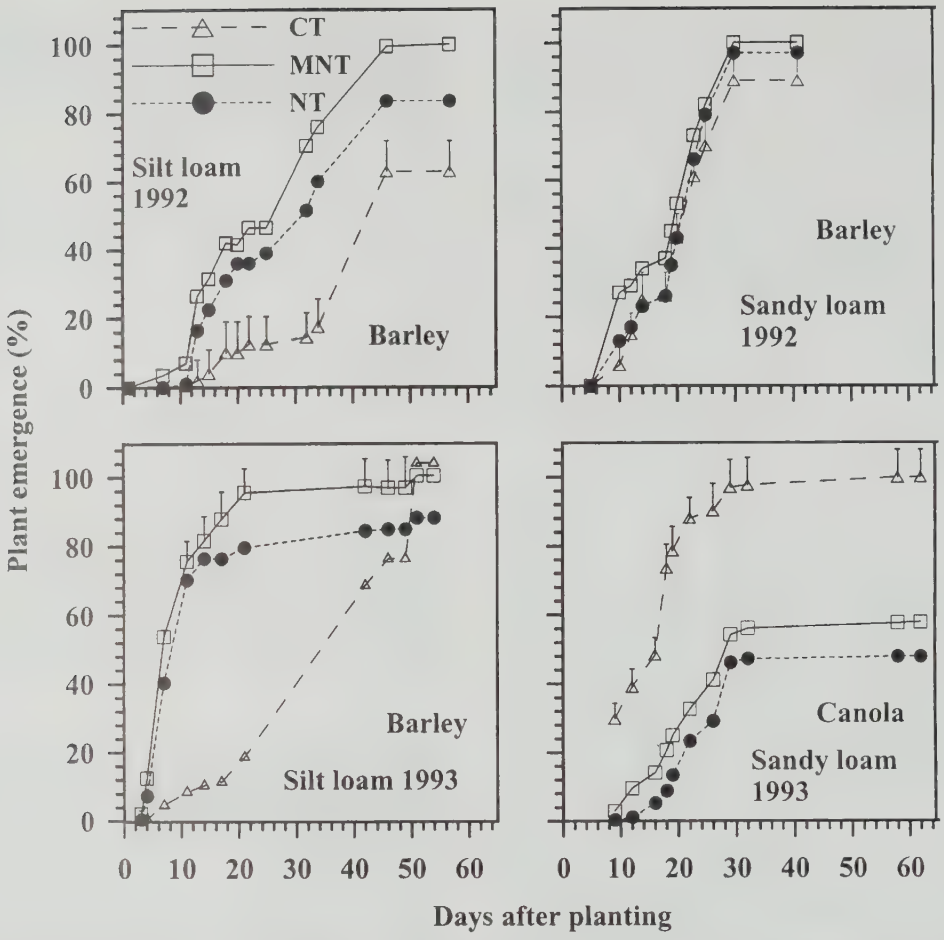


**Figure 5. Barley and canola emergence as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) at the Dawson Creek (silt loam) and Rolla (sandy loam) sites. The vertical bars represent the LSD at $P \leq 0.05$.**

years cannot be fully accounted for by soil temperature alone. The MNT treatment resulted in slightly lower seed zone temperature (Fig. 3), significantly greater soil moisture (Fig. 2), and most likely better seed–soil contact than CT treatment. The spring tillage in CT plots resulted in a loose seed-bed, causing poor seed–soil contact early during the drought period. This indicates that soil moisture, previous crop residue placement in-between the rows and good seed–soil contact played important roles in determining barley emergence in the silt loam soil during early stages of the dry period.

The slower emergence rate for canola under NT and MNT treatments as compared with CT could be due to lower seed zone temperature during the germination period (Tables 1, 2 and Fig. 3, note: soil temperatures were measured only in the silt loam soil). In a previous study, Kondra et al. (1983) found that the rate of germination of canola declined rapidly with decreasing temperature.

## *Barley and canola growth*

Low soil moisture content, along with high maximum and daily average soil temperature during the first 3 weeks after planting in 1992 and 1993 created an environment which was more stressful to barley under all treatments. This resulted in relatively small differences in the early growth stages on both sites. Cumulative barley dry matter in the silt loam soil in 1992 at 49 days after planting (stage 5 on Feekes scale of barley growth, just before stem extension begins) was significantly higher under MNT as compared to the CT and NT treatments; however, these difference became non-significant toward maturity (Fig. 7). On the sandy loam soil in 1992 at 50 days after planting, the barley dry matter was 1.62 Mg ha$^{-1}$ in CT, 2.08 Mg ha$^{-1}$ in MNT and 1.80 Mg ha$^{-1}$ in NT, all significantly different among these three treatments. The general trend observed in 1992 was MNT > NT > CT; this trend was more evident on sandy loam soil at the Rolla site, where MNT and NT had significantly higher barley dry matter at 70 days after planting (growth stage 8) compared to CT treatments. This could be due to improved soil moisture conservation in the residue treatments, during a relatively dry period. In 1993, the barley dry matter at 47 days after planting was 0.45 Mg ha$^{-1}$ in CT, 1.55 Mg ha$^{-1}$ in MNT and 1.41 Mg ha$^{-1}$ in NT for the silt loam soil at Dawson Creek site. The barley dry matter in CT was significantly lower than in MNT and NT at this growth stage. However, toward maturity (after stage 10 at Feekes scale), this trend reversed and resulted in significantly higher barley dry

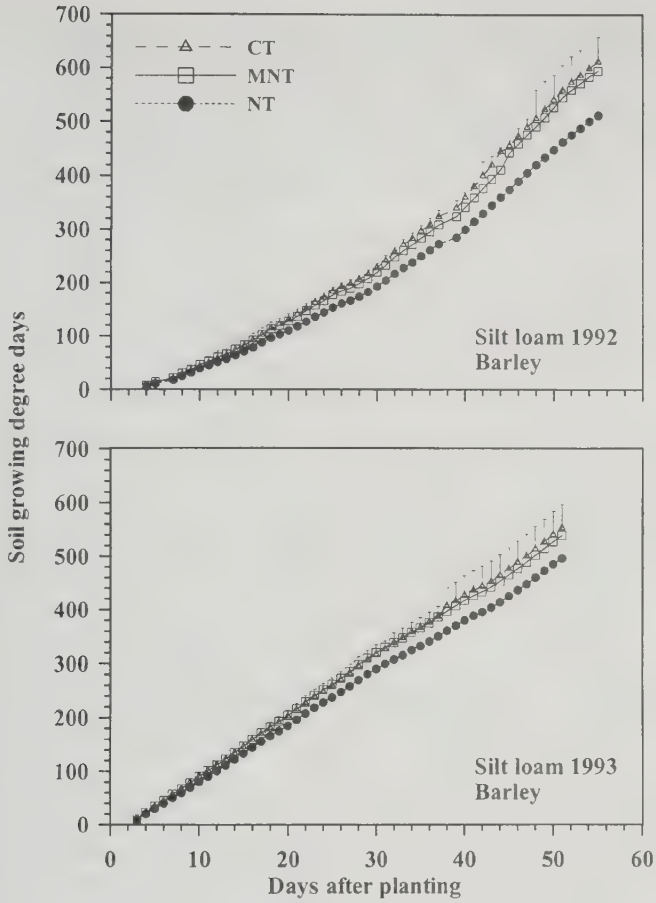


**Figure 6. Soil growing degree days (SGDD) as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) in the silt loam soil at Dawson Creek. The vertical bars represent the LSD at $P \leq 0.05$.**

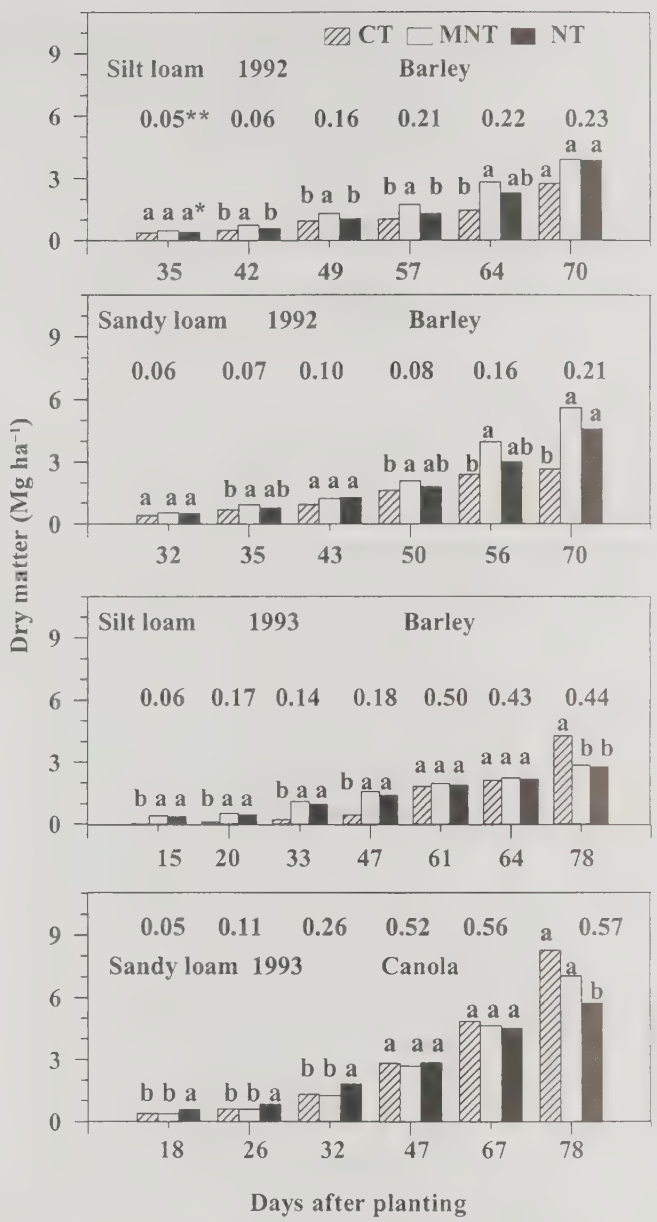


**Figure 7. Accumulation of above-ground dry matter early in the growing season as affected by residue management in conventional tillage (CT), no-tillage (NT) and modified no-tillage (MNT) at the Dawson Creek (silt loam) and Rolla (sandy loam) sites. * = Means followed by the same letter are not significantly different according to LSD at $P \leq 0.05$. ** = Standard error.**

matter under CT than in MNT and NT (Fig. 7). Wet soil conditions adversely affected plant development. This depressed barley growth, leading to lower barley dry matter in NT and MNT compared with CT in 1993 (Fig. 7). Our data reported earlier (Azooz and Arshad, 1998) showed that the barley grain yield ranged from 1.74 to 1.78 Mg ha$^{-1}$ in NT, 1.70 to 1.81 Mg ha$^{-1}$ in MNT, and from 1.44 to 2.88 Mg ha$^{-1}$ in CT during 1992 and 1993 for the silt loam soil at Dawson Creek. For the sandy loam soil at Rolla, the barley grain yields were 1.80 Mg ha$^{-1}$ in NT, 1.70 Mg ha$^{-1}$ in MNT and 1.43 Mg ha$^{-1}$ in CT in 1992. The grain yields for canola were 0.99 Mg ha$^{-1}$ in NT, 1.12 Mg ha$^{-1}$ in MNT and 1.22 Mg ha$^{-1}$ in CT in 1993. Our recent study on another site in this region showed that the wheat grain yield (3-year average) under MNT was approximately 10% higher than for the NT system (Arshad et al., 2002).

In 1993, the cumulative canola dry matter during the first 67 days after planting (growth stage 5 at Feekes scale) in the sandy loam soil at the Rolla site was 4.85 Mg ha$^{-1}$ in CT, 4.66 Mg ha$^{-1}$ in MNT and 4.51 Mg ha$^{-1}$ in NT. There were no significant differences in canola dry matter among different treatments during 47–67 days after planting, although canola under all treatments was affected by excessive soil moisture (Figs. 1 and 2). Afterward, there was a significant increase in canola dry matter yield under CT and MNT compared to NT (Fig. 7). The canola growth was more depressed in the NT than MNT, likely caused by the lower temperature during the wet period, resulting in a significantly lower canola dry matter in the NT treatment. The general pattern of canola dry matter from 67 days after planting to the end of the growing season was CT > MNT > NT with a significantly lower yield in NT.

The differences in seed emergence and dry matter production of barley and canola among the three tillage

systems in 1992 (dry year) and 1993 (wet year) show that early crop establishment depended not only on soil temperature but also on the level of moisture stored in the soil in the dry and wet periods during the growing season.

The MNT treatment with a residue-free zone performed better than NT under excessive soil moisture conditions and cooler soil temperatures, as evident from cumulative dry matter and grain yield trends observed for both barley and canola in 1993. The differences were more obvious in canola than barley (Fig. 7).

## Conclusions

This study indicates that, in areas where soil temperature and moisture limit crop establishment in no-tillage systems (NT), removing crop residue from the planting rows (MNT) can enhance early crop emergence. Our data show that the 7.5 cm wide residue-free band over the rows of spring barley and canola resulted in more favorable seed-zone temperatures than the NT system, and improved soil moisture conditions compared with the conventional tillage (CT) system. Overall, the MNT system was beneficial for seed emergence and early plant growth and development during prolonged periods with little or no precipitation, as compared to CT. However, grain yield of barley was still lower in the NT and MNT than CT system at both sites in 1992 and 1993. Further studies are needed to find an optimum width for residue-free zones for narrow-row crops and to develop suitable machinery for creating residue-free zones. A negative impact on crop production with no-tillage practices was observed under prolonged wet periods, due to greater ability to retain water by soil under NT and MNT compared with CT. Compared with NT, the MNT system also had a more positive effect on canola emergence, cumulative dry matter and grain yields under extremely wet soil conditions. This study demonstrates that in-row residue removal is an effective way to improve soil warming and early crop establishment, and thus consequently improve dry matter and grain yield in no-tillage spring crop production systems in cold semi-arid regions with a short growing season.

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# Improving the nutrient status of a commercial dairy farm: An integrated approach

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Abstract. *Minimizing nutrient surpluses and improving efficiency of nutrient use are key challenges for all dairy farming production systems, driven by economic, environmental and increasing regulatory constraints. Our study examined the efficiency of N, P and K use on a commercial dairy farm through an integrated approach that evaluated the nutrient status of all aspects of the production system of the case-study farm, a 75 lactating Holstein cow dairy in Kings County, Nova Scotia, Canada. During the decade after 1988, the farm owner implemented a series of changes in production practices, including diversification of the crop rotation, implementation of a management intensive grazing (MIG) regime and adoption of a systematic approach to soil and nutrient management. Milk production, and associated farm exports of N, P and K, increased by 666 kg cow$^{-1}$ between 1990 and 2000. Purchases of N–P–K fertilizers were eliminated in 1990 and feed nutrient imports were dramatically reduced. Feed costs per liter of milk declined from 14.3 cents (CDN) liter$^{-1}$ in 1990–92 to 11.6 cents liter$^{-1}$ in 1998–2000, even as feed prices increased regionally by 10–20% over the same period. Modeling of current whole farm mass N, P and K balance indicated that 25.0% of all N inputs are recovered in farm products, milk and meat. Non-legume-derived field N input (67 kg N ha$^{-1}$ before losses) was close to optimum for the predominantly legume/grass-based forage cropping system. Model-determined annual farm nutrient surpluses (outputs–inputs) for P (9.0 kg ha$^{-1}$ yr$^{-1}$) and K (8.2 kg ha$^{-1}$ yr$^{-1}$) were significantly lower than those previously reported for regional confinement-based dairy farms, which were more reliant on corn production. However, data from 16 years of soil analysis (1985–2001) indicated an increase in soil-test P levels of approximately 2 mg kg$^{-1}$ yr$^{-1}$. Recent refinements in dairy animal dietary P levels have further reduced the farm P surplus (2.6 kg ha$^{-1}$ in year 2001) and are shown as key to a strategy for reversal of the trend in soil-test P levels. In summary, the combined approach of whole-farm system nutrient management, crop diversification and MIG increased milk production and minimized costs while reducing farm nutrient inputs. The study demonstrates how an approach to dairy farm nutrient management which integrates livestock and crop nutrient requirements may reduce dairy farm nutrient loading while maintaining productivity.*

Key words: animal nutrition, dairy, management intensive grazing, nutrient budgets

## Introduction

Most dairy farms produce large nutrient surpluses, with less than 30% of all N, P and K inputs exported in animal products, primarily as a result of high feed nutrient inputs relative to outputs in milk (Anderson and Magdoff, 2000; Klausner, 1995; Klausner et al., 1998). Dairy production systems reliant on high levels of feed and fertilizer nutrient inputs run the risk of nutrient loading and increased nutrient losses to the environment (Hutson et al., 1998; Yiridoe and Weersink, 1998). The widespread adoption of regulations restricting nutrient loading may have important implications with respect to animal density on farms, cropping composition and dairy production systems (Anderson and Magdoff, 2000; Beegle et al., 2000; Schmit and Knoblauch, 1995; Sims, 1995). The trend in the Atlantic Canada dairy industry is towards consolidation into larger herds combined with infrastructure development geared towards higher production per cow. Technological advances have been made in mechanical harvesting and feeding systems, and ensiling forage as a component of total mixed ration (TMR) for confined feeding is now common. However, the consequent increased importation of fertilizer and feed, combined with significant overfeeding of nutrients such as P, has contributed to increasing nutrient surpluses on many dairy farms (Knowlton et al., 2001; Powell et al., 2001). As the cost of inputs continues to rise and as liberalization of world trade causes milk prices to fall for Canadian farmers, reducing input costs is also an economic opportunity.

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The reduction in feeding costs and dependence on purchased nutrient inputs associated with increased use of legumes in forage production (Jarvis et al., 1996; Laws et al., 2000), and management intensive grazing (MIG) (Anderson and Magdoff, 2000; Fredeen et al., 2002; Hanson et al., 1998) have important implications with respect to the efficiency of dairy farm nutrient use. MIG attempts to optimize pasture productivity by rotational stocking of pastures on the basis of target sward entrance and exit heights (Murphy, 1998). Pasture is an important crop in Atlantic Canada (Papadopolous et al., 1993) and while an increasing body of research suggests dairy farm net returns and economic performance may be improved through MIG (Fredeen et al., 2002; Hanson et al., 1998; Parker et al., 1992) its adoption remains low among dairy farms in eastern Canada (Clark et al., 1993).

Alternative dairy farming production systems (including MIG and the reliance on forage $N_2$ fixation in place of purchased fertilizer N) may reduce dairy farm nutrient surpluses and pollution potential, but these benefits may be offset by significant reductions in both animal and crop production. The following case study documents the 13-year transition of a commercial dairy farm to a pasture-based dairy production system, and the impact of these changes in management system on livestock productivity, costs of production, and whole farm and soil nutrient status. A primary objective was to evaluate the opportunities, on a commercial dairy farm, for implementing an integrated approach to farm nutrient management that attempts to closely integrate livestock and crop nutrient requirements with soil nutrient status while maintaining a high level of productivity.

## Materials and Methods

### Farm description

Kipawo Holsteins is a 75 cow (*Bos taurus*), 132 ha dairy farm located in Grand Pre, near Wolfville, Nova Scotia, Canada. There are 54 owned and 25 rented hectares of Acadia silty clay (Gleyed Regosol) and 32 owned and 21 rented hectares of predominantly Pugwash-Cornwallis loam soil (Orthic Humo-Ferric Podzol). The region receives approximately 1200 mm precipitation annually with average corn (*Zea mays* L.) heat units of 2500 (Anonymous, 1991; Brown, 1978). The herd comprised 75 registered Holsteins in a free-stall slatted-floor barn. Cows are fed a mixture of haylage and corn silage in the feed bunk which is accessible year round. Dairy concentrate is offered at a rate of 1 kg concentrate (14% crude protein) per 3 kg milk during the winter months and 1 kg concentrate per 4.5 kg milk when cows are on pasture. Cows producing more than 23 kg milk $day^{-1}$ receive between 0.5 and 3 kg $day^{-1}$ of an additional protein and energy supplement (32% crude protein) offered in four computerized feeding stalls.

Until the late 1980s, the crop sequence consisted of 4–5 years of a haylage mixture of either alfalfa (*Medicago sativa* L.) or red clover (*Trifolium pratense* L.) and a forage grass (*Phleum pratense* L. or *Bromis inermis* Leyss.) followed by 1 or 2 years of corn. In 1988, the farmer dramatically reduced corn hectarage and eliminated all purchases of N–P–K fertilizers. These changes were not driven by cash-flow problems, but by an intuitive sense that reducing nutrient inputs could be cost-effective and environmentally beneficial. The crop rotation was broadened to include small-grain cereals and, in 2000, included a total of 17.2 ha of wheat (*Triticum aestivum* L.), winter rye (*Secale cereale* L.), and barley (*Hordeum vulgare* L.). The cereal crops serve as a companion crop for newly seeded forage crops, as a source of straw for livestock bedding and, as of November 2000, small grains are milled on-farm and used in dairy ration formulation. The remaining land is primarily in alfalfa/grass/red clover mixtures for haylage. In 1998, the farmer revisited growing silage corn (12–15 ha in both 2000 and 2001) as a high-volume forage crop adapted to the increasingly arid summer climate and as an excellent energy supplement for grazing dairy cows. Between 1992 and 1996 a management intensive grazing (MIG) system was adopted and the herd was moved to a day and night grazing regime extending from late April to early November. In 2000, approximately 34% of the farm hectarage was divided into MIG paddocks. Pastureland is predominantly perennial ryegrass (*Lolium perenne* L.), orchard grass (*Dactylis glomerata* L.) and white clover (*Trifolium repens* L.). Some of the pastures are harvested as first-cut haylage. Between 1990 and 1998, in response to an increased frequency of drought, the farm land base was increased by 21 ha.

In 1985 a systematic program of soil testing the entire farm every 2–3 years was adopted. Fertility recommendations were geared towards using on-farm resources to meet predominantly legume-based crop requirements. There was a trend away from dolomitic limestone ($CaMgCO_3$, 22% Ca, 11% Mg) to using more gypsum ($CaSO_4$, 27% Ca, 18% S) and calcitic lime ($CaCO_3$, 32% Ca, 3% Mg). Manure from the milking herd is stored in pits directly under the slatted floor of the barn. A weatherproof composting facility was constructed in 1997 to compost heifer manure with chopped straw bedding for application to soils testing low in organic matter. A land rental agreement with a local poultry farmer obligated the case-study farm owner to import approximately 75 Mg (fresh wt.) of poultry broiler manure annually, a practice that was discontinued at the end of the 2000 growing season.

### Data collection

Monthly Atlantic Dairy Livestock Improvement Corporation (ADLIC) reports provided herd production data in addition to amounts of forage, concentrates and supplements consumed. Using a commercial total mixed ration (TMR) feed mixer and scale, weights of haylage,

corn silage, concentrates and supplements were recorded before feeding. The nutrient composition of feed imports (dairy concentrates, mineral supplements and kelp meal) fed was obtained from feed analysis reports and suppliers. Information regarding the target nutrient composition of dairy rations was obtained from the farm's feed consultant.

In 2000, yields of all hay, haylage, corn silage and grain were recorded. Samples of feeds were obtained at harvest. Haylage, hay and pasture samples were oven-dried (55°C), ground (1 mm), and crude protein was determined by N combustion (Leco FP–228 Analyzer). Pasture intake was estimated monthly (coinciding with ADLIC test days) using the method of Haydock and Shaw (1975), whereby five 0.5 × 0.5 m quadrats ($n = 5$) per paddock, representing the range of biomass on offer, were sampled and weighed before and after grazing. Total intake was determined by visually ranking (on a scale of 1–5) the remainder of the paddock ($n = 100$ quadrats) before and after grazing. Percentage hectarage in legumes was determined from farm records and by visual evaluation of legume content of all fields during soil sampling.

Soil tests (Mehlich-3; 0–15 cm depth) were conducted on all fields in early May, 2001. Results of whole-farm soil analysis for previous years (1998, 1996, 1993 and 1985) were obtained from the soil and nutrient management consultants to the farm, and the farmer. Farm-produced liquid manure was sampled immediately prior to application. The average liquid dairy manure nutrient analysis for 2000–2001 is presented, along with that obtained for imported chicken (*Gallus domesticus*) manure, in Table 1. The quantity and composition of all imported seed was also recorded.

## Modeling nutrient flows

Whole-farm mass nutrient balances for N, P and K were determined for 2000. Exports of these elements in milk were determined from the amount and protein content of milk sold, and assuming 0.90 g P $kg^{-1}$ milk (Powell et al., 2001) and 1.10 g K $kg^{-1}$ milk (Maynard et al., 1979). No animals were imported to the farm, and no manure was exported. The N, P and K exported in meat was estimated from the number and average weight of cull cows or calves sold and assuming exported meat, on a live weight basis, contained 2.08% N (Maynard et al., 1979), 0.075% P (Anderson and Magdoff, 2000) and 0.015% K (Maynard et al., 1979).

Total N derived from $N_2$ fixation (6953 kg N $yr^{-1}$) was estimated by assuming 50% crop recovery of all manure N inputs (Fig. 1) and subtracting manure, N deposition and seed N field inputs from the total annual crop N offtake (11,346 kg N $yr^{-1}$; Fig. 1). Annual grass/clover hectarage plowed for corn production ranges from 12 to 15 ha. Based on an estimate of 120 kg N $ha^{-1}$ of residual N available for corn production in the year following forage plowdown (Shelby and Sandman, 1997), annual plowed hectarage provides a total N credit of 1200–1500 kg N $yr^{-1}$. Thus, the total of 6953 kg N derived from $N_2$ fixation is comprised of 5653 kg fixed N in harvested feed plus a 1300 kg plowdown N credit. Visual ranking of percent legume per field in May 2001 indicated an average of 40.6% clover or alfalfa in pasture and forage stands and, as cropping mix remains virtually stable between years, this estimate of legume production was taken as representative of yearly averages. Averaged across the farm's 132 ha, 6953 kg N $yr^{-1}$ requires an average annual rate of $N_2$ fixation of 52.7 kg N $ha^{-1}$, a figure well within regional estimates of $N_2$ fixation per ha by clover or alfalfa in mixed stands (Anonymous, 1991).

Combined atmospheric (wet and dry) N deposition was estimated at 6.1 kg N $ha^{-1}$ $yr^{-1}$ (B. Beattie and R. Vet, Atlantic Region Office of Environment Canada,

**Table 1. Dairy manure and imported chicken manure nutrient analysis.**[1]

| | Dairy manure[2] | | Chicken manure[2] |
|---|---|---|---|
| **Component** | **Average[3]** | **SD[4]** | **Average[3]** |
| Dry matter (%) | 11.21 | ± 0.70 | 37.40 |
| Total N (%) | 0.38 | ± 0.03 | 1.30 |
| Ammonium-N (%) | 0.20 | ± 0.04 | 0.31 |
| Total P (%) | 0.07 | ± 0.01 | 1.55 |
| Total K (%) | 0.43 | ± 0.09 | 0.73 |
| N:P ratio | 5.4:1 | – | 1.3:1 |

[1] Fresh weight basis.
[2] Imported in 2000.
[3] Average of three samples, taken August 2000, June 2001 and October 2001.
[4] SD = standard deviation.

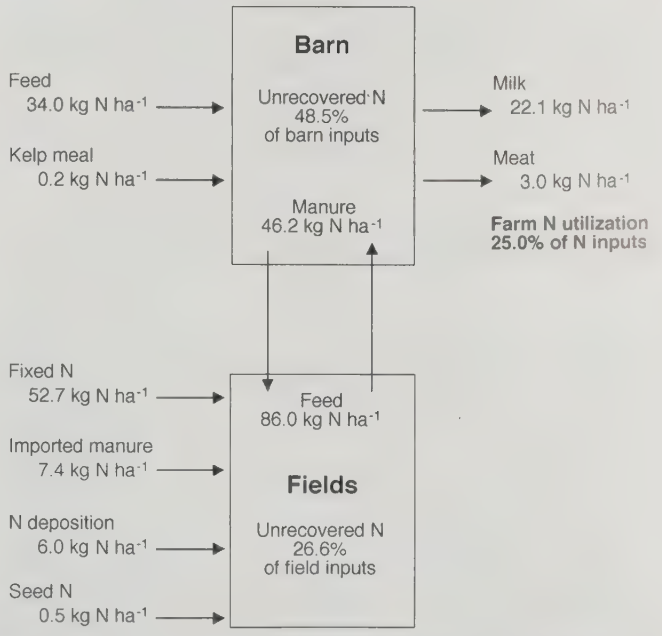


**Figure 1. Farm nitrogen inputs and outputs, and within-farm N flows for year 2000.**

Dartmouth, Nova Scotia, personal communication, June 1, 2001). The estimate was based on measurements of long-distance atmospheric N transport from the Environment Canada Monitoring Station at Kejimkujik Park, South Central Nova Scotia. The largest components included wet $NO_3$ deposition (2.25 kg N $ha^{-1}$ $yr^{-1}$), wet $NH_4$ deposition (1.06 kg N $ha^{-1}$ $yr^{-1}$) and $HNO_3$ (1.04 kg N $ha^{-1}$ $yr^{-1}$). As direct measurements of dry $NH_3$ and dry $NO_2$ were unavailable, we included a value for dry $NH_3$ (0.98 kg N $ha^{-1}$ $yr^{-1}$) as measured for a similar agricultural region in Sutton, Quebec. Dry $NO_2$ deposition was estimated as approximately half that at Sutton (0.18 kg N $ha^{-1}$ $yr^{-1}$) as recent satellite imagery has shown the lower atmosphere burden of $NO_2$ in Nova Scotia is approximately half that in Quebec. The total estimated N deposition of 6.1 kg N $ha^{-1}$ $yr^{-1}$ is approximately one-third of the total N deposition estimate of 18.4 kg N $ha^{-1}$ $yr^{-1}$ by Barry et al. (1993) for southern Ontario, due to much lower values for dry $NO_2$, wet $NO_3$ and wet $NH_4$.

The percent utilization of total farm input N, P or K in outputs (i.e., farm products of milk and meat) was calculated, using the steady state model of Paul and Beauchamp (1995), as:

% N, P or K output utilization = 100 × (total N, P or in K exported in products/total N, P or K imported).

The annual N, P or K remainder or surplus is expressed as a percentage of inputs and per ha. The amount of dairy manure N produced on farm annually (including manure directly deposited on pasture) was calculated using typical values for daily output by dairy animals (37.0 kg per 454 kg animal) (OMAF, 1985; Shelby and Sandman, 1997) and the manure N content as indicated by analyses when leaving storage (4.1 kg N $Mg^{-1}$) (Table 1). This figure (5543 kg N) was increased by 10% to allow for dilution of manure N content by milkhouse and barn waste water during storage. Within-farm N flows to field and barn (manure and feed N) are presented in Figure 1. Unrecovered N for barn and field farm components (primarily manure N losses in storage and following field application) was calculated as:

% N unrecovered = 100 × [total barn (or field) N inputs − total barn (or field) N outputs] ÷ total farm N inputs

(Paul and Beauchamp, 1995). We assumed losses of P and K associated with the liquid manure storage and weather-proof manure composting facility to be negligible. Two assumptions of the steady-state model used to determine the case-study farm nutrient budget, i.e., that animal numbers remained constant and that feed was not produced in surplus, were met. Considering that the current cropping system of predominantly clover/grass forage and pasture has been maintained for over 13 years on the case-study farm, we also assumed a steady-state level of soil organic matter (and soil N) when averaged across the whole farm. Franzlubbers et al. (2000), however, demonstrated that in humid regions, long-term pastures maintained under improved management may significantly increase soil storage of C and N. As discussed below, the potential exists that an additional benefit of adoption of a MIG system and expansion of farm hectarage in permanent pastures may be an annual accrual of soil C and N, with significant implications for model estimates of farm N use efficiency.

## Results and Discussion

### Livestock performance and costs of production

Milk production increased 666 kg, from a 3-year average of 8370 kg $cow^{-1}$ in 1990–92 to 9036 kg $cow^{-1}$ from 1998 to 2000 (Table 2). Herd production of milk (kg) and percentages of butterfat (BF) and crude protein (CP) compare favorably with provincial averages (Table 2; ADLIC, 2001). Farm feed costs per liter of milk produced decreased from 14.3 cents (CDN) $liter^{-1}$ in the 1990–92 period to 11.6 cents $liter^{-1}$ in 1998–2000. By comparison, feed costs provincially averaged 14.2 cents $liter^{-1}$ for the years in which data are available during the decade 1990–2000 (Table 2; ADLIC, 2001). Prices for feed and prepared feed in Atlantic Canada rose between 10 and 20%

**Table 2. Herd performance and feed costs, 1990–2000.**

| | Year | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Productivity indices** | **1990** | **1991** | **1992** | **1993** | **1994** | **1995** | **1996** | **1997** | **1998** | **1999** | **2000** |
| Herd production (kg milk $cow^{-1}$ $yr^{-1}$) | 8272 | 8809 | 8029 | 8703 | 8094 | 8273 | 8215 | 8510 | 8989 | 9189 | 9036 |
| Provincial average | na[1] | na | 7869 | 7996 | 8132 | 8248 | 8275 | 8456 | 8542 | 8577 | na |
| Milk fat (%) | 3.74 | 3.80 | 3.78 | 3.93 | 3.84 | 3.63 | 3.73 | 3.65 | 3.57 | 3.55 | 3.61 |
| Provincial average | na | na | 3.67 | 3.69 | 3.71 | 3.68 | 3.66 | 3.66 | 3.65 | 3.71 | na |
| Milk protein (%) | 3.22 | 3.28 | 3.21 | 3.18 | 3.17 | 3.14 | 3.16 | 3.20 | 3.21 | 3.10 | 3.06 |
| Provincial average | na | na | 3.28 | 3.23 | 3.22 | 3.22 | 3.2 | 3.23 | 3.23 | 3.23 | na |
| Feed costs[2] (cents $liter^{-1}$) | 15.3 | 13.4 | 14.2 | 12.9 | 13.3 | 12.6 | 11.1 | 12.2 | 10.6 | 11.4 | 12.8 |
| Provincial average | 15.0 | 15.1 | 14.1 | 14.8 | 14.3 | 14.6 | na | 14.0 | 12.0 | na | na |

[1] na = not available.

[2] Actual average feed costs (in Canadian dollars), unadjusted for inflation.

in the period 1990–98 (NSDAF, 1999). At concentrate prices of \$200 (CDN) to \$250 $Mg^{-1}$, 14.0 cents $liter^{-1}$ is an expected average feed cost for confinement fed herds (Main, 2001). Farm receipts indicate purchased feed costs totaled \$40,120 (CDN) in year 2000, down from \$95,283 in 1998 and a high of \$126,562 in 1990. Milk production per cow fluctuated in the years coinciding with the transition to MIG, 1992–96, most likely due to a decrease in grain consumption. The production decrease during transition to MIG is within the range of 3–10% reported by Hanson et al. (1998) from a study of 60 dairy farms that switched to intensive grazing systems in the Pennsylvania–New York state border region. Difficulties in estimating intake on pasture and its impact on ration balancing may account for production decreases during transition to a MIG system (Parker et al., 1992). The farm land base was significantly increased (by 21 ha or 19%) in the period following conversion to MIG (1993–98). This increase in farm size is in keeping with other reports of decreased livestock-carrying capacities of 16–25% for unfertilized legume-based cut or grazed forages compared with forages receiving mineral N fertilizer (Jarvis et al., 1996; Laws et al., 2000; Leach et al., 2000).

## Nutrient mass balance and soil nutrient status

The increase in milk exports per cow from the case-study farm over the past decade, combined with an increased reliance on farm-produced feeds and virtual elimination of all fertilizer imports, indicates a marked improvement in farm nutrient use efficiency in both animal and crop production. In addition, a decade after foregoing purchases of N–P–K fertilizer, there are no obvious signs that soils on the case-study farm are nutrient deficient (Table 3). It is the high feed nutrient inputs relative to outputs, however, rather than fertilizer inputs, on dairy farms that generate the large nutrient surpluses. In a study of 17 New York state dairy farms widely ranging in the number of cows per farm, Klausner et al. (1998) found that the percentage of imported N, P and K annually remaining on these farms ranged from 61–76%, 59–79% and 67–89%, respectively, with purchased feed as the dominant source of nutrient inputs. Individual nutrient management practices, particularly with respect to ration balancing but also cropping system and nutrient management practices, rather than farm size *per se*, determined annual nutrient surpluses. The N, P and K mass balance calculated for the case-study farm for year 2000 (Table 4) indicated the annual percentages of N, P and K inputs, not exported as milk and meat, to be 75.0%, 68.8% and 62.9%, respectively. The latter value, the percent K remaining per year, in particular, is slightly lower than the K surplus range of 67–89% of K inputs reported by Klausner et al. (1998), but still represents, on a per ha basis, an annual surplus of 8.2 kg K $ha^{-1}$ $yr^{-1}$. While soil-test K levels have moderated across the farm over the past 16 years (Table 3), soil-test levels on most fields remain adequate for forage production, and forage regularly tests close to 3% K.

Reliance on legume $N_2$ fixation where possible, and reduced reliance on managed flows of imported N and other non-renewable resources, is an important indicator of the environmental sustainability and resilience of a farm. The farm's N output utilization (recovery in milk and protein products) of 25% of all farm N inputs is well within the typical range (16–30%) of N output utilization by dairy cows, irrespective of N input source (biological $N_2$ fixation or mineral N) (Jarvis et al., 1996; Klausner et al., 1998; Paul and Beauchamp, 1995). The estimated N not accounted for in exported animal products (75.0% of the total annual farm N inputs), therefore, is on the same order of magnitude as more purchased-input intensive production systems. The total annual N surplus of 9979 kg N $yr^{-1}$ is approximately 30% greater than that estimated for farms of comparable herd size by Klausner (1995). However,

**Table 3. Soil nutrient status in year 1985 and 2001 for farm fields[1] held in both years.**

| | Year | | | |
|---|---|---|---|---|
| | 1985 | | 2001 | |
| Nutrient | Average | SD[3] | Average | SD[3] |
| OM (%) | 3.3 | ± 1.1 | 3.9 | ± 0.8 |
| Ca (mg $kg^{-1}$)[2] | 1293 | ± 246 | 1488 | ± 206 |
| Mg (mg $kg^{-1}$)[2] | 568 | ± 219 | 279 | ± 86 |
| K (mg $kg^{-1}$)[2] | 291 | ± 176 | 166 | ± 62 |
| P (mg $kg^{-1}$)[2] | 117 | ± 47 | 151 | ± 90 |

[1] $n$ = 32 fields, averaging 80% of total farm hectarage.
[2] Mehlich–3 extractable.
[3] SD = standard deviation.
OM, organic matter.

**Table 4. Whole farm mass nitrogen, phosphorus and potassium balance, for year 2000.**

| Production component | Nitrogen | Phosphorus | Potassium |
|---|---|---|---|
| Inputs | | kg $yr^{-1}$ | |
| Purchased feed | 4492 | 970 | 1076 |
| Purchased seed | 60 | 7 | 10 |
| Purchased kelp meal | 30 | 5 | 95 |
| Imported manure | 974 | 746 | 545 |
| $N_2$ fixation | 6953 | – | – |
| N deposition | 797 | – | – |
| Outputs | | | |
| Milk | 2922 | 525 | 641 |
| Meat | 402 | 14 | 3 |
| | | % of total inputs | |
| Output utilization | 25.0 | 31.2 | 37.3 |
| Remainder | 75.0 | 68.8 | 62.9 |
| | | kg $ha^{-1}$ $yr^{-1}$ | |
| Remainder | 75.6 | 9.0 | 8.2 |

because of the reduced animal density (0.76 animal units per hectare) the N surplus is a relatively low 75.6 kg $N\,ha^{-1}\,yr^{-1}$ compared to estimates of 142.2 kg $N\,ha^{-1}\,yr^{-1}$ for 85 cow herd farms provided by Klausner (1995). Jarvis et al. (1996) estimated surpluses for four reduced N input model dairy farming systems of 132–202 kg $N\,ha^{-1}\,yr^{-1}$. As noted above, the possibility exists that a large proportion of the total farm N inputs unaccounted for may be immobilized in soil organic matter, particularly under permanent pastures. Increases in soil N storage of up to 70 kg $N\,ha^{-1}\,yr^{-1}$ over a 10-year period under sod or permanent pasture have been documented (Barry et al., 1993; Franzlubbers et al., 2000). Such a rate of N accrual, if ascribed to only the pasture hectarage (44.9 ha or 34% of total farm hectarage) would increase the farm N utilization rate of all N inputs to 48.6% and reduce estimated annual farm N losses to 51.8 kg $N\,ha^{-1}\,yr^{-1}$. Among the production strategies available to further increase farm N use efficiency, improvements in dietary N utilization by dairy cattle during both confinement and grazing will have the greatest impact (Jones-Endsley et al, 1997; Paul and Beauchamp, 1995; Rotz et al., 1999), but at present many of these dietary refinement strategies remain to be demonstrated as economically viable. Jarvis et al. (1996) suggest that for dairy farming systems reliant on biological $N_2$ fixation, inclusion of an optimum level of corn silage production (approximately 20% of total hectarage) in the cropping mix can further minimize N losses per livestock unit.

Ceasing all purchases of N–P–K fertilizers has generated an annual saving of up to $10,000 (CDN) per annum for the case-study farm. With the exception of the imported concentrate and imported waste poultry manure (the latter input was discontinued in year 2000) the farm appears to be self-sufficient in N. Total non-legume-derived field N inputs, including within-farm dairy manure N flows (6097 kg N, Fig. 1) supply an average of 67 kg $N\,ha^{-1}\,yr^{-1}$ (excluding corn hectarage) before field losses. An additional input of up to 12 kg $N\,ha^{-1}\,yr^{-1}$ is provided by the release of residual N from previous manure applications (Shelby and Sandman, 1997). Regional recommended N application rates for haylage mixtures are from 20 kg $N\,ha^{-1}\,yr^{-1}$ (60% or more legume content) to 100 kg $N\,ha^{-1}\,yr^{-1}$ (30–60% legume content) (Anonymous, 1991). Further indications that N is not deficient on the case-study farm are that in 2000 yields of barley (3.5 Mg $ha^{-1}$) and first-cut haylage (4.6 Mg dry matter $ha^{-1}$, average of nine fields) were within or above the respective average values for the region (Anonymous, 1991). Maintaining sufficient available sulfur can also enhance forage nitrogen use efficiency and reduce N leaching losses (Brown et al., 2000). While not examined specifically, the potential exists that the routine use of gypsum (which supplied 40 kg $S\,ha^{-1}$ in 1996 and 100 kg in 1992) and maintenance of high levels of soil-test sulfur (28 ppm $SO_4$-S average across nine fields tested in 2001) is further contributing to crop N use efficiency on the case-study farm.

Unaccounted for N in the barn was calculated at 48.5% of all barn N inputs compared with losses of 26.6% from all field N inputs (Fig. 1). Losses of 40% or more of N inputs in dairy animal facilities from wasted feed and volatilization of $NH_3$-N from manure prior to collection and during storage are not uncommon (Paul and Beauchamp, 1995). Actual barn percent N losses may be slightly lower than calculated because, for simplicity, pasture N flows were included within flows of feed and manure to and from the barn. Crop recovery of 50% of applied N in the year of application may be considered a typical upper limit for both fertilizer N and dairy manure N (Paul and Beauchamp, 1995; Shelby and Sandman, 1997). The relatively low field-associated N losses of 26.6% in the case-study farm are attributable to the high proportion of field N inputs (46.7%) derived from $N_2$ fixation. Field unrecovered N represented 47.4% of N inputs for the dairy farm examined by Paul and Beauchamp (1995) when legume-fixed N supplied only 29% of total N inputs to the fields.

By maintaining the pasture sward in the vegetative state, crude protein levels and organic matter digestibility of intensively managed pastures are expected to be higher and to contain less senesced forage than extensively managed pastures or hay or haylage (Paine et al., 1999). In 2000, the most productive pasture paddocks on the case-study farm were rotated through ten grazing cycles per season. Crude protein of pasture samples obtained immediately prior to grazing averaged 22.6% (seasonal range 17.3–26.0% CP) which is significantly higher than mechanically harvested feed values. Haylage regularly tests between 14 and 18% crude protein (average of seven first-cut haylage samples, 13.38% CP; range 11.95–15.25% CP). An examination of the N use efficiency comparing MIG and confinement feeding was beyond the scope of this study. While concentrate costs decreased during the grazing season (May–October) in 2000, milk crude protein levels were also somewhat reduced. While an MIG-based system substantially reduces the volume of manure requiring storage, and thus avoids N losses associated with manure management while allowing for a generally even distribution of the manure across the grazed pastures (White et al., 2001), these N management benefits may be offset by exacerbated field losses of both gaseous N ($N_2O$, $NH_3$) and leached N ($NO_3$) from pastures, due to the high concentrations of N in urine patches (Hutchings and Kristensen, 1995; Oenema et al., 1997; Stout et al., 2000). Improvements in estimating intake on pasture and optimizing ration balancing offer the best opportunity for maximizing pasture N use efficiency (Jones-Endsley et al, 1997; Rotz et al., 1999).

While the past decade has seen a marked decrease in N, P and K imports on the case-study farm, the annual surplus of 9.0 kg $P\,ha^{-1}\,yr^{-1}$ for 2000 (Table 4), combined with high (31–50 mg $kg^{-1}$; 69–112 kg $ha^{-1}$) to excessive (>50 mg $kg^{-1}$; >112 kg $ha^{-1}$) Mehlich–3 soil-test P on most of the farm fields (Table 3), remained of particular concern from an

environmental perspective. In addition, regulations requiring a P-based approach to nutrient management in many jurisdictions may severely constrain the management options available to producers whose fields already test well in excess of crop requirements for soil available P (Anderson and Magdoff, 2000; Schmit and Knoblauch, 1995; Sims, 1995).

In Table 5 the farm's characteristics are compared with those in a survey conducted by Anderson and Magdoff (2000) of 46 northeastern US dairy farms grouped by operation category. The animal density (0.76 AU $ha^{-1}$) of the case-study farm is slightly lower than average for the pasture-based farms, while the herd production (9036 kg milk $cow^{-1}$ $yr^{-1}$) is more characteristic of the more intensive, confinement-based farms. The case-study farm annual P surplus (9.0 kg P $ha^{-1}$ $yr^{-1}$) is substantially lower than the average reported by Anderson and Magdoff (2000) for confinement-based farms (36.7 kg P $ha^{-1}$ $yr^{-1}$) and slightly less than the P surplus typical of pasture-based farms (11.3 kg P $ha^{-1}$ $yr^{-1}$). While the relationship between annual farm P surpluses and trends in soil-test P levels will vary depending on the soil P adsorption capacity, Powell et al. (2001) suggest an increase of 1 ppm $yr^{-1}$ in soil-test P (Bray 1) may be expected for dairy farms maintaining an annual P surplus of 8.8 kg P $ha^{-1}$ $yr^{-1}$. This lower rate would be an improvement in the average rate of increase in soil-test P of closer to 2 ppm $yr^{-1}$ obtained for the case-study farm (Table 3) over the past 16 years.

While reducing manure N losses during storage and handling will improve the manure N:P ratio, typical dairy dietary P levels produce manures with low N:P ratios compared to crop uptake requirements (N:P 8:1 to 14:1; Kelling and Matocha, 1990). As a result, relying on manure alone as a N fertilizer source contributes to an oversupply of P (Powell et al., 2001; Sims, 1995). The N:P ratio of the farm dairy manure analyzed averaged 5.4:1 in 2000–2001 (Table 1). In contrast, the chicken manure imported until 2000 had a very narrow N:P ratio of 1.3:1.

As noted by Powell et al. (2001) and Klausner et al. (1998), the failure to integrate existing knowledge, rather than a lack of sufficient scientific information, appears to be the main hindrance to gains in nutrient use efficiency and the development of comprehensive dairy farm nutrient management plans. For example, any effective long-term strategy to address soil P loading on the case-study farm, will of necessity require efforts directed at refining dietary P levels. The case-study farm is currently maintaining herd production at close to 9000 kg milk $yr^{-1}$ from 75 cows with feed P imports of 975 kg feed P $yr^{-1}$ or 13.0 kg feed P $cow^{-1}$ $yr^{-1}$. Dairy cow dietary P levels on the case-study farm for 2000 were maintained at close to 5.0 g P $kg^{-1}$ dry matter. These figures compare closely with those of Powell et al. (2001), who assessed annual feed P inputs of 12.91 kg P $cow^{-1}$ $yr^{-1}$ if dietary P is maintained at 4.8 g P $kg^{-1}$ for a 100 cow dairy producing at 9100 kg per 305-day lactation. Concentrate use is expected to be reduced further as the farm becomes more self-sufficient in grain, and feed P imports will be comprised of primarily an inorganic P supplement (dicalcium phosphate). In 2001, through consultations with the dairy feed consultant to the farm, target dietary P levels were reduced by 10% to 4.5 g P $kg^{-1}$ of diet dry matter. Combined with the cessation of imports of chicken manure, P surpluses per ha for year 2001 were estimated to be reduced to 2.6 kg P $ha^{-1}$ $yr^{-1}$ (total P imports of 885 kg $yr^{-1}$ minus exports of 539 kg $yr^{-1}$, per 132 ha) (Table 5). In subsequent years, a further gradual reduction in dietary P levels to the level of approximately 4.0 g P $kg^{-1}$ of diet dry matter, as recommended by Powell et al. (2001) and Wu et al. (2001), combined with an expansion of the corn silage hectarage to an optimum level for grazing animal energy requirements, should provide the combined benefits of enhanced crop uptake and on-farm cycling of P and depletion of excessive soil P levels.

## Conclusions

While detailed data collection is required, the study demonstrates that only by combined evaluation of the nutrient status of the soil and crop and animal components of a dairy farm, can the full impact of adoption of a new

**Table 5. Phosphorus surplus in relation to dairy production system.[1]**

| Production system | *n* | Farm size (ha) | Animal density (AU $ha^{-1}$)[2] | Herd production (kg milk $cow^{-1}$ $yr^{-1}$) | % land in corn | Imported feed and mineral P (kg $ha^{-1}$ $yr^{-1}$) | Imported manure or fertilizer P (kg $ha^{-1}$ $yr^{-1}$) | Net P surplus (kg $ha^{-1}$ $yr^{-1}$)[3] |
|---|---|---|---|---|---|---|---|---|
| Confinement farms | 20 | 192.3 | 2.00 | 9455 | 42.2 | 32.4 | 15.9 | 36.7 |
| Pasture-based[4] | 23 | 94.3 | 1.22 | 6973 | 7.4 | 12.5 | 4.7 | 11.3 |
| Case-study farm (2000) | 1 | 132.4 | 0.76 | 9036 | 11.4 | 7.5 | 5.7 | 9.0 |
| Case-study farm (2001) | 1 | 132.4 | 0.76 | 9036 | 11.4 | 6.8 | 0.0 | 2.6 |

[1] Adapted from Anderson and Magdoff (2000).
[2] AU = one animal weighing 454 kg.
[3] Surplus = net farm P accumulation (imports-exports) per ha farm land base.
[4] Lactating herds on pasture a minimum of 5 months per year.

production system be evaluated, and significant improvements in farm nutrient use efficiency be realized. The case-study farm implemented a marked shift in production practices, including foregoing the use of commercial NPK fertilizers and the transition to a MIG regime, without causing a long-term decrease in milk yields. This willingness to implement significant changes in the dairy production system, combined with an integrated approach to nutrient management, which includes improvements in ration formulation, is providing both economic and environmental benefits with respect to both farm profitability, farm nutrient use efficiency and farm resiliency. A less comprehensive or more tactical approach, such as the adoption of best management practices or nutrient planning for specific components of the production system, is less likely to have achieved the sustained benefits documented. However, the increased reliance on grazing, and on $N_2$ fixation and manure for crop nutrient inputs, because of the inherent variability of nutrient supply from these sources, presents a challenge to further improvements in nutrient use efficiency. Research that refines our ability to assess and optimize the contributions of these on-farm resources will play a critical role in improving the future sustainability of dairy farming systems.

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# The performance of organic and conventional cropping systems in an extreme climate year

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Abstract. *The 1999 severe crop season drought in the northeastern US was followed by hurricane-driven torrential rains in September, offering a unique opportunity to observe how managed and natural systems respond to climate-related stress. The Rodale Institute Farming Systems Trial has been operating since 1981 and consists of three replicated cropping systems, one organic manure based (MNR), one organic legume based (LEG) and a conventional system (CNV). The MNR system consists of a 5-year maize–soybean–wheat–clover/hay rotation, the LEG of a 3-year maize–soybean–wheat–green manure, and the CNV of a 5-year maize–soybean rotation. Subsoil lysimeters allowed quantification of percolated water in each system. Average maize and soybean yields were similar in all three systems over the post-transition years (1985–1998). Five drought years occurred between 1984 and 1998 and in four of them the organic maize outyielded the CNV by significant margins. In 1999 all crop systems suffered severe yield depressions; however, there were substantial yield differences between systems. Organic maize yielded 38% and 137% relative to CNV in the LEG and MNR treatments, respectively, and 196% and 152% relative to CNV in the soybean plots. The primary mechanism of the higher yield of the MNR and LEG is proposed to be the higher water-holding capacity of the soils in those treatments, while the lower yield of the LEG maize was due to weed competition in that particular year and treatment. Soils in the organic plots captured more water and retained more of it in the crop root zone than in the CNV treatment. Water capture in the organic plots was approximately 100% higher than in CNV plots during September's torrential rains.*

Key words: organic agriculture, organic farming drought resistance, crop water, hydrology

## Introduction

Long-term crop yield stability and the ability to buffer yields through climatic adversity are critical factors in agriculture's ability to support society in the future. Global climate change has brought about predictions of increased instability in climatic conditions, leading to increased incidence and severity of droughts, flooding and other extreme climatic events (Sombrock and Gommes, 1996; Weiss and Bradley, 2001). Organic crop systems in North America have been shown, on the average, to yield approximately 90% to 95% of conventional crop systems (Lotter, 2003). Where organic crop systems excel, however, is in water- and climate-stress situations. A number of studies have shown that under drought conditions, crops in organically managed systems produce higher yields than comparable crops managed conventionally (Dormaar et al., 1988; Stanhill, 1990). This advantage can result in organic crops outyielding conventional crops by 70–90% under severe drought conditions (Lockeretz et al., 1981; Petersen et al., 1999; Wynen, 1994). Others have shown that organically managed crop systems have lower long-term yield variability, i.e., higher cropping system stability (Henning, 1994; Peters, 1994; Smolik et al., 1995). Swift (1994) proposed that assessments of crop performance should include analysis of two components—yield and stability of yield–from one climatic cycle to the next.

Several mechanisms may increase drought tolerance of organic cropping systems. The higher water-holding capacities found in organically managed soils (Liebig and Doran, 1999; Wells et al., 2000) may be the major one. Numerous studies have shown soil organic carbon (C) to be higher in organically managed systems (Clark et al., 1998; Drinkwater et al., 1995; Liebig and Doran, 1999; Petersen et al., 1999; Reganold, 1995; Reganold et al., 1993). Plant water uptake and ability to withstand drought are significantly improved by mycorrhizal associations (Syliva and Williams, 1992). Mycorrhizae have been shown to be more abundant in the roots of crops from organically managed systems relative to those of conventionally managed crops (Eason et al., 1999; Mader et al., 2000; Ryan et al., 1994). This suggests both a physico-

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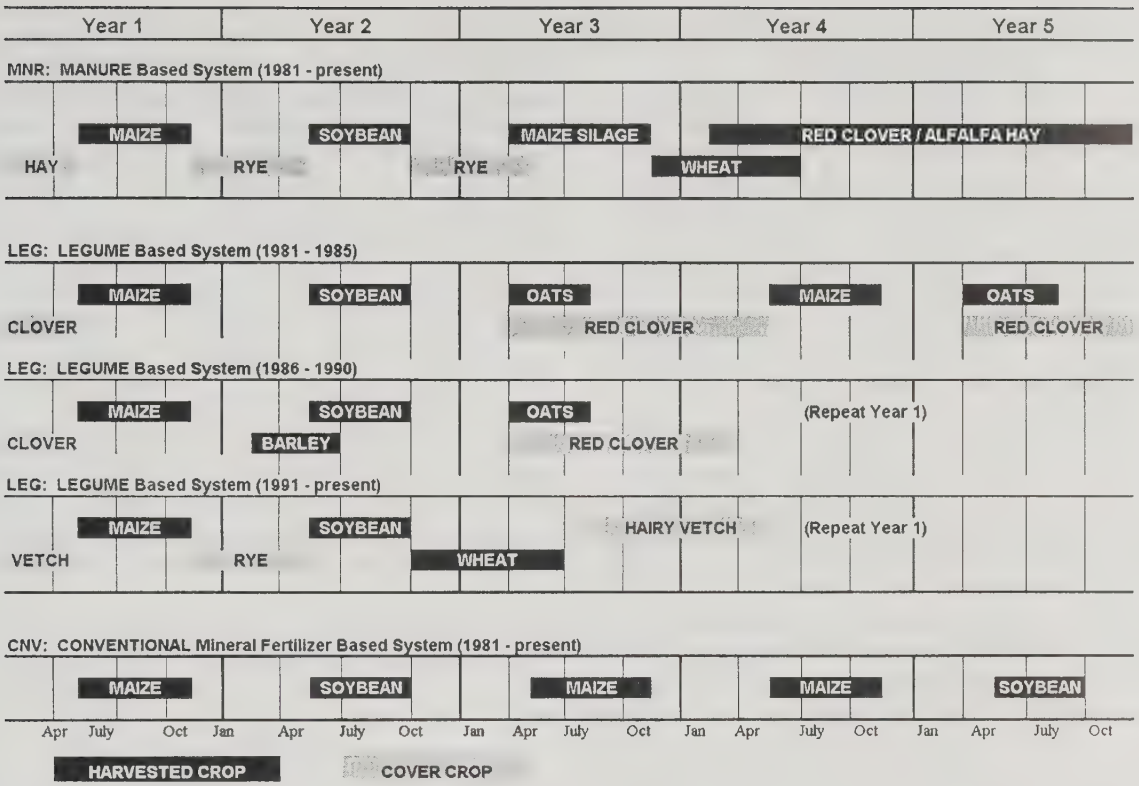


**Figure 1. The Rodale Farming Systems Trial rotations. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic. In each system the nitrogen input is added before the maize crop: MNR, steer manures and red clover/alfalfa plow down; LEG, legume plow down (red clover or hairy vetch); CNV, mineral fertilizer. The rye cover crop was added as a catch crop to the MNR rotation in 1992 and to the LEG rotation in 1993.**

chemical and biological basis for the increased drought tolerance of organic cropping systems.

The mitigation of runoff, erosion and crop losses as a result of rainfall excess, a serious agricultural constraint (Jaenicke, 1998; USDA, 1994), is also improved in organically managed systems. Organic management of soils leads to improved soil stability and resistance to water erosion compared to conventionally managed soils, due to higher soil C content and improved soil aggregation (Clark et al., 1998; Drinkwater et al., 1995; Liebig and Doran, 1999; Reganold, 1995; Reganold et al., 1993), permeability (Fleming et al., 1997; Gerhardt, 1997; Petersen et al., 1999; Reganold et al., 2001) and lower bulk density (Gerhardt, 1997; Liebig and Doran, 1999; Reganold et al., 1993), as well as higher resistance to wind erosion (Jaenicke, 1998). Comparisons of erosion rates in organic versus conventional systems, show significantly lower erosion in organically managed systems. Lockeretz et al. (1981) reported one-third less erosion from Midwest organic farms than from comparable conventionally managed farms. Fleming et al. (1997) showed that the K-factor (soil erodibility) of the revised universal soil loss equation was reduced in organically managed systems.

Organic cropping systems have been reported to outyield conventionally managed systems in situations of rainfall excess and climate extremes. In 1993, Japan's conventional rice crops were nearly wiped out by an unusually cold summer, while organically farmed rice yielded 60–80% of the annual average (Anon., 1994). In Central America over 1800 farms using organic and sustainable methods were the subject of a comparison study, using paired conventional neighbor farms, of the effects of Hurricane Mitch. Farms using organic and sustainable methods reported substantially lower economic losses, and 90% of the neighbors of the study farms indicated a desire to adopt their neighbors' methods after observing the environmental stress tolerance of the organic/sustainable farms (Holt-Gimenez, 2002).

Other studies have reported that under flooded conditions organically managed crops have outyielded conventionally managed crops, due to higher levels of water-stable aggregates in organic soils and associated reduced soil compaction after spring tillage (Denison, 1996). A survey of 208 projects in developing tropical countries in which contemporary organic practices were introduced showed average yield increases of 5–10% in irrigated crops and 50–100% in rainfed crops (Pretty and Hine, 2001).

The Rodale Farming Systems Trial was initiated in 1981 in order to compare the benefits and risks of three farming systems, two organic—manure based (MNR) and legume based (LEG)—and one conventional (CNV), on a long-term basis. Basic data on water capture, nutrient and pesticide leaching, yields, and crop and soil nutrient status have been collected. Crop system performance during years of climatic stress is a particularly important area, given the

Table 1. Rodale Farming Systems Trial inputs for the 1999 crop season.

| | N source | Cover crop seeding rate (kg ha$^{-1}$) | Cover crop planting date | Incorporation date | Cover crop or fertilizer inputs (kg ha$^{-1}$) | Cover crop or fertilizer % N | Total N input[1] (kg ha$^{-1}$) | Main crop seeding rate (seeds ha$^{-1}$) | Main crop planting date |
|---|---|---|---|---|---|---|---|---|---|
| Maize | | | | | | | | | |
| CNV[2] | Mineral fertilizer[3] | – | – | 4/27/1999 | 112 | 30 | 34 | | |
| | | | | 6/18/1999 | 373 | 30 | 112 | 64,000 | 4/27/1999 |
| LEG | Hairy vetch | 36 | 8/25/1998 | 4/30/1999 | 5425 | 5.18 | 281 | 64,000 | 5/12/1999 |
| MNR | Hay[4] | 11.2/5.6 | 3/3/1997 | 4/13/1999 | 1469 | 3.52 | 52 | | |
| | Steer manure | – | | 4/13/1999 | 5355 | 3.44 | 184 | 64,000 | 5/12/1999 |
| Soybean | | | | | | | | | |
| CNV | – | – | – | – | – | – | – | 432,000[5] | 5/26/1999 |
| LEG | – | 157 | 11/9/1998 | 5/5/1999 | 1019 | 2.42 | 24.7 | 494,000 | 5/27/1999 |
| MNR | – | 157 | 11/9/1998 | 5/5/1999 | 1294 | 2.28 | 29.5 | 494,000 | 5/27/1999 |

[1] Total N inputs between the organic (MNR and LEG) and CNV differ substantially, given the low percentage availability of organic N.
[2] CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.
[3] Mineral fertilizer for CNV corn is applied as starter fertilizer at planting time and side dressed at 12 inches tall.
[4] Hay is a mix of red clover and alfalfa.
[5] Soybeans in the CNV system are planted in 18-cm rows, in MNR and LEG systems in 76-cm rows.

evidence that climatic stress and variation is on the increase (Sombrock and Gommes, 1996). In this paper, by looking at crop and water dynamics during a climatic stress season within a multiple year experiment, we provide evidence that conversion to organic agriculture may provide increased long-term food production sustainability. The 1999 crop season in the northeast US was unique, with a prolonged crop season drought followed by heavy rainfall. These two stress factors, drought and torrential rains, serve to illustrate differences in the sustainability of the two crop systems.

## Materials and Methods

### Experimental site, treatment and design

The study was conducted on the 6.1 ha Farming Systems Trial (FST) at the Rodale Institute in Berks County, southeastern Pennsylvania. The soil is primarily Comly silt loam with 12% Berks shaly silt loam and a small area of Duffield silt loam. Annual precipitation is 1080 mm, with 50% occurring from May 1 to September 30. The annual average temperature is 12.4°C, summers are hot and humid, winters are relatively short and mild. The growing season is 180 days long, with 1600 growing degree days (based on 10°C).

Beginning in 1981, three farming systems were established: (1) manure-based organic (MNR); (2) legume-based organic (LEG); and (3) conventional (CNV) (Fig. 1). The purpose was initially to examine the process of converting from a conventionally managed cropping system to an organically managed system and to quantify the long-term changes in the sustainability and profitability of these systems.

The MNR system assumes a livestock component, and utilizes manure for fertilization. It consists of a 5-year maize (*Zea mays* L.)–soybean (*Glycine max* L. Merr)–maize silage–winter wheat (*Triticum aestivum* L.)–hay [red clover (*Trifolium pratense* L.) and alfalfa (*Medicago sativa* L.)] rotation.

The LEG system does not include an animal component but produces cash grain crops every year, using a plow-down legume as a nutrient source in the 3-year maize–soybean–wheat rotation. Both the MNR and LEG systems rely on mechanical cultivation and heterogeneous crop mixes for their weed and pest control.

The CNV system is a cash grain system using mineral fertilizer and pesticides in its 5-year maize–soybean rotation. Fertilizers and pesticides in the CNV system are applied according to recommendations by Pennsylvania State University. Maize and soybeans are common to the three systems. Seeding rates, biomass and N inputs, and planting dates for the three treatments are shown in Table 1.

The experimental design is a split-plot randomized complete block design with eight replications. Main plots are 18 × 91.5 m. To allow same crop comparisons in any year, each rotation main plot is split into three 6 × 91.5 m subplots and the main rotation was begun at three different crop entry points. Grass buffer strips (1.5 m wide) between the systems minimize cross movement of soil, fertilizers and pesticides.

## Sampling methods

The parameters measured were cover crop and crop biomass, weed biomass, grain yields, percolated water volumes, soil water content and water infiltration rates.

Maize grain yields were assayed by mechanically harvesting the center four rows of each plot. Soybean and wheat yields were obtained by mechanically harvesting a 2.4 m swath in the center of each plot.

In four of the eight replications in each cropping system a 76 cm long by 76 cm diameter steel cylinder lysimeter was installed in the fall of 1990, to enable the collection of percolated water (Fig. 2). The top of each lysimeter was approximately 36 cm below the soil surface to allow field operations to be carried out in a normal fashion directly over the lysimeters. Approximately 20 holes were drilled in the center of the base plate, to allow for unrestricted flow of percolate from the cylinder into the flexible tube leading to the collection device, a 20-liter polyethylene carboy. Two more tubes were connected to the carboy: the air tube, which ran from the cap of the carboy to the soil surface, and a second tube, which ran from the base tubulation fitting of the carboy to the soil surface and served as the extraction tube for the percolate. The extraction tube was capped with a garden hose fitting; the air tube was capped with a two-way aluminum breather to allow airflow into the carboy during leachate extraction. The carboy was positioned below and offset to one side of the steel cylinder to enable gravitational flow of liquid to the collection device. Any percolate flowing from the cylinder into the carboy was collected via a marine utility pump connected to the extraction tube (Moyer et al., 1996). Water could not escape from the lysimeter system. Leachate samples were collected throughout the year. In 1999, the number of samplings was reduced due to the lack of precipitation during the summer.

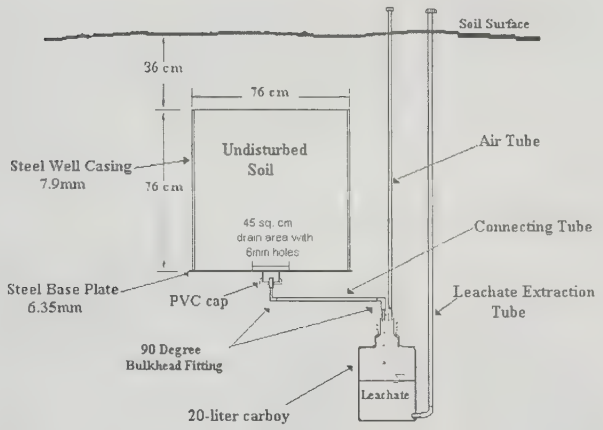


**Figure 2. Lysimeter used to collect percolated water and leachate under plots in each treatment in the Rodale Farming Systems Trial.**

Soil water content was determined gravimetrically on sieved soil (2 mm) from samplings taken in the LEG and CNV systems in June and October 1998 (in maize) and in May and October 1999 (in soybean).

Statistical analyses were performed with the General Linear Model Univariate procedure of SPSS software version 10.1.3 (SPSS, Inc., Chicago, IL).

## Results and Discussion

Average yields of maize and soybeans from 1985 to 1998 were relatively equal between the three treatments, with a small but statistically significant underyield in the organic soybean treatments (Table 2). The 1986–1990 LEG soybeans were a relay crop and underyielded compared to full-season soybeans. When these years are not included in

**Table 2. Average yields of organic maize and soybean in the Rodale Farming Systems Trial 1985–1998 compared to a conventionally managed system.[1]**

| Crop and management system[2] | $N$[3] | Yield (kg ha$^{-1}$) | SD[4] | Relative to CNV |
|---|---|---|---|---|
| Maize | | | | |
| MNR | 63 | 7107 a | 1448 | 105% |
| LEG | 111 | 7001 ab | 1452 | 103% |
| CNV | 198 | 6757 b | 1717 | 100% |
| Soybean | | | | |
| MNR | 64 | 2638 b | 466 | 95% |
| LEG[5] | 112 | 2332 c | 838 | 84% |
| CNV | 135 | 2770 a | 379 | 100% |

[1] Yields followed by a common lower-case letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.
[2] CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.
[3] Number of crop seasons × replications.
[4] Standard deviation.
[5] The 1986–1990 LEG soybeans were a relay crop and underyielded compared to full-season soybeans. When these years are not included in the mean, LEG soybean yields are not significantly different from those of CNV soybeans.

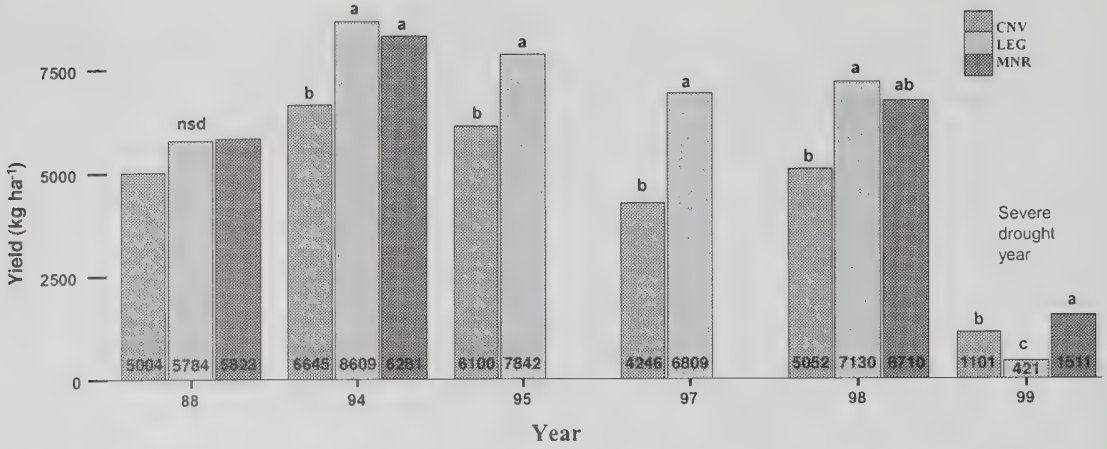


**Figure 3. Maize yields in drought years (total April to August rainfall less than 350 mm). Different letters above bars in the same cluster denote statistical significance at the 0.05 level. Letters denoting significance are for one year only. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.**

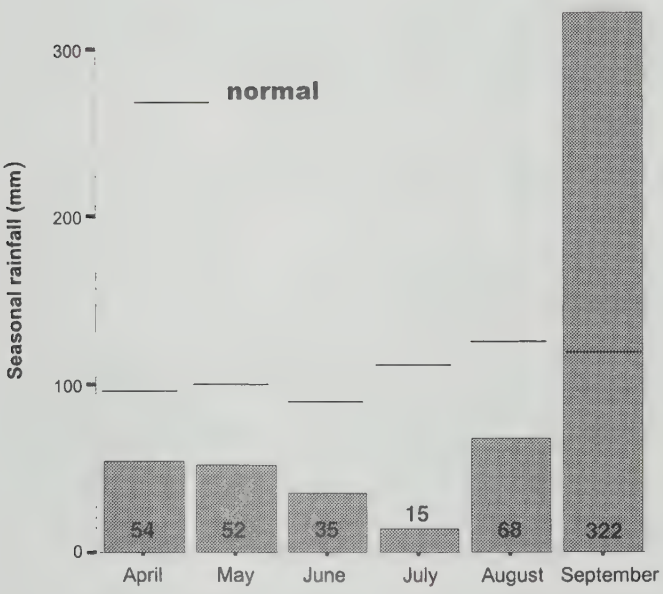


**Figure 4. Crop season monthly rainfall at the Rodale Farming Systems Trial site, 1999.**

the mean, LEG soybean yields are no different than the CNV soybeans. In four out of the five drought years (total April–August rainfall less than 350 mm) MNR and LEG maize outyielded CNV by a significant margin (Fig. 3). This gave us impetus to look at the 1999 severe drought year more closely.

Crop season rainfall for April, May, June, July and August 1999 at the FST (Fig. 4) were 55%, 66%, 17%, 29% and 40% of normal for those months, respectively. September 1999, with 268%, was a complete reversal of previous months as a result of Hurricane Floyd, and was the wettest September on record in the Northeast. September precipitation for weather stations across the 12 state region averaged 182 mm (7.16 in), which is nearly double (199%) the monthly normal. In Berks County over 200 mm of the month's 350 mm of rain fell in a 3-day period, with 91 mm in a 12-h period on September 16. Table 3 summarizes the crop system dynamics and performance for the three systems.

## Drought and yield

Due to drought, maize and soybean yields were severely reduced in 1999 to less than 20% of the long-term average in maize and 60% in soybean. Relative to CNV, 1999 maize yields in the MNR and LEG treatments were 50% higher and 66% lower, respectively (Fig. 5). Soybean yields were 35% and 96% higher in the MNR and LEG, respectively, than in the CNV treatment.

**Maize**. Severely reduced yields in the LEG maize plots were largely due to weed pressure and to excessive cover crop biomass in that year, both of which consume limited soil water, the cover crop before maize planting and the weeds during the growing season. The primary weed species was foxtail (*Setaria* spp.) within the maize rows. The hairy vetch (*Vicia villosa* Roth) cover crop in the LEG maize, planted fall 1998, measured 5425 kg ha$^{-1}$ (dry weight) when incorporated on April 30, 1999. This was nearly twice that needed for adequate N inputs of 150 kg N ha$^{-1}$. Conditions for growth of hairy vetch were ideal in fall and spring, and the vetch crop was the highest yielding ever in the FST. This coincided with the subsequent drought, and soil water depletion by the high level of cover crop biomass was likely partially responsible for the maize crop water stress later in the season. Additionally, dry conditions during early maize growth, as a result of soil water use by the abundant vetch crop, allowed foxtail, which can outgrow maize under these conditions, to outcompete maize and reduce its yield.

The residue of highly soluble N from the vetch as a result of the poor maize growth in 1999, which normally takes up the excess N, also gave rise to higher than normal leachable

**Table 3. Relative performance of the three crop systems—manure-based (MNR), legume-based (LEG) and conventional (CNV)—during the 1999 season of drought followed by a major storm event.**

| System | Crop/soil situation | Relative performance | Late-season flood performance |
|---|---|---|---|
| Maize | | | |
| MNR | Low to moderate biomass of both spring cover crop and weed population, plus good water infiltration and soil water holding capacity gives optimum drought adaptiveness | Good | Good: good water capture, reduced runoff |
| LEG | High biomass spring cover crop and weeds overuse water and overcome benefits of good soil water-holding capacity and infiltration, causing crop failure | Very poor | Good: good water capture, reduced runoff |
| CNV | Poor soil water-holding capacity and infiltration limit ability of crop to adapt to drought despite negligible water use by weeds and no water use by a cover crop | Intermediate | Poor: poor water capture high runoff |
| Soybean | | | |
| MNR | Low weed and spring cover crop biomass and good soil water infiltration and water-holding capacity give optimum drought adaptiveness | Good | Good: good water capture, reduced runoff |
| LEG | Low weed and spring cover crop biomass and good soil water-holding capacity and infiltration gives optimum drought adaptiveness | Good | Good: good water capture, reduced runoff |
| CNV | Poor soil water-holding capacity and infiltration limit ability of crop to adapt to drought despite negligible water use by weeds and no water use by a cover crop | Poor | Poor: poor water capture high runoff |

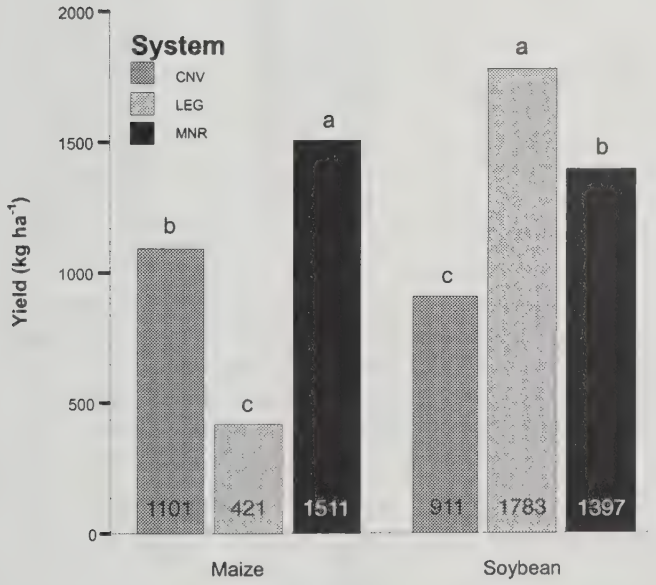


**Figure 5. Maize and soybean grain yields in conventional (CNV), legume-based (LEG) and manure-based (MNR) plots, 1999. Different letters above bars in the same cluster denote statistical significance at the 0.05 level.**

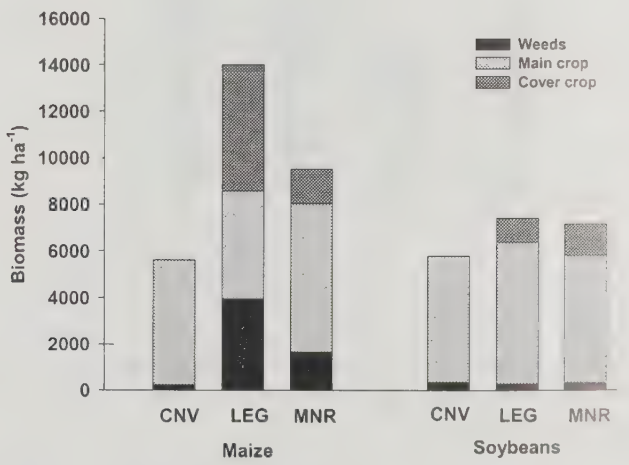


**Figure 6. Total standing biomass (weeds, cover crop and main crop) in the three systems in two crops. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.**

nitrates during the 1999–2000 winter. Rye (*Secale cereale* L.) is planted in the fall after maize as a catch crop for excess N. However, the September torrential rains leached the excess nitrates before the rye was planted. The N budget will be the subject of another paper.

The MNR maize had a fall-planted red clover/alfalfa hay cover crop incorporated on April 13, measuring 1469 kg ha$^{-1}$ (approximately 25% of the biomass of the LEG hairy vetch cover crop). Weeds were not a problem in the MNR treatment.

The total plant biomass for the main crop (at harvest) cover crop (at spring plowing) and weeds (late season) for maize and soybean are shown in Figure 6. Counting the maize crop, cover crop and weeds, the LEG system in 1999 supported nearly three times the plant biomass of the CNV system.

August weed biomass (the only weed sampling date) in the LEG maize plots was nearly equal to the maize biomass, and was over double that of MNR weed biomass

and over 15 times higher than weeds in the CNV plots. Maize biomass yields were much closer between systems in 1999 than maize grain yields, indicating that water stress in the LEG treatment occurred at the critical grain-filling stage in August.

**Soybean**. LEG soybean yields were significantly higher than MNR, and MNR in turn yielded significantly higher than CNV. In contrast to the LEG maize, the LEG soybean crop had fall-planted rye as a spring cover. The LEG soybean cover crop had only about one-fifth of the biomass (1019 kg ha$^{-1}$) as the LEG maize cover crop (Fig. 6, Table 1), and was comparable to the rye cover crop in the MNR soybean (1294 kg ha$^{-1}$).

Weed levels in the soybean plots were low in all three systems, at around 300 kg ha$^{-1}$, less than 10% of the weed biomass in the maize LEG treatment.

## Water dynamics

Data collected over the past 10 years of the FST experiment show that the MNR and LEG treatments improve the soils' water-holding capacity, infiltration rate and water capture efficiency. LEG maize soils averaged a 13% higher water content than CNV soils at the same crop stage, and 7% higher than CNV soils in soybean plots (Fig. 7).

Water capture, as represented by percolated water harvested from the lysimeters, averaged 30% higher in the MNR and LEG plots than in the CNV plots in 1999 (Fig. 8), and in September, following high rainfall, the MNR system captured over two times as much water as the CNV plots, and the LEG only slightly less than two times the CNV (Fig. 9). In May, at the onset of drought, the CNV

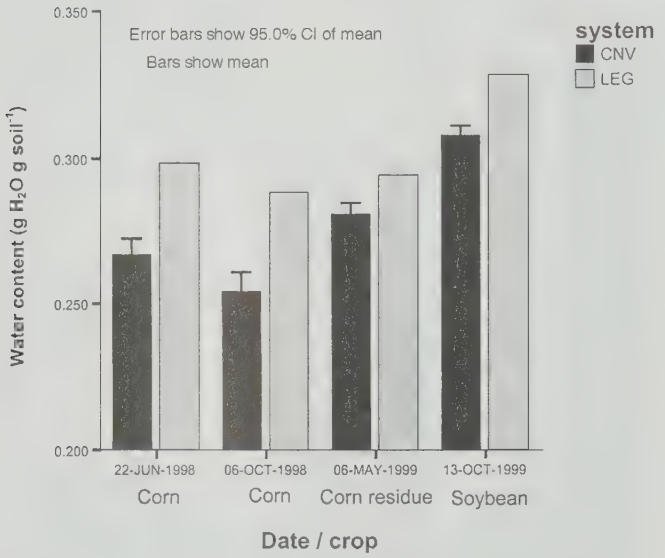


**Figure 7. Water content of soils in organic and conventional cropping systems. MNR was not part of this analysis. CNV, conventional management; LEG, legume-based organic; CI, confidence interval.**

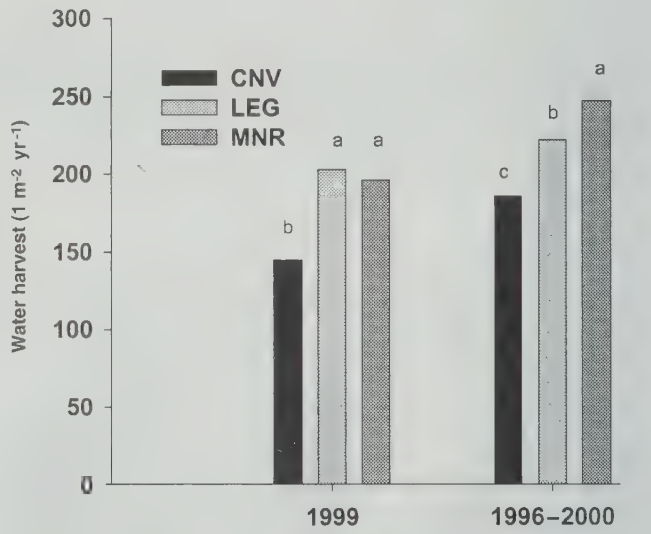


**Figure 8. Percolated water harvested in 1999 and the average of 1996–2000 from the three crop systems in the Rodale Farming Systems Trial. Letters denoting significance are for one set of bars only. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.**

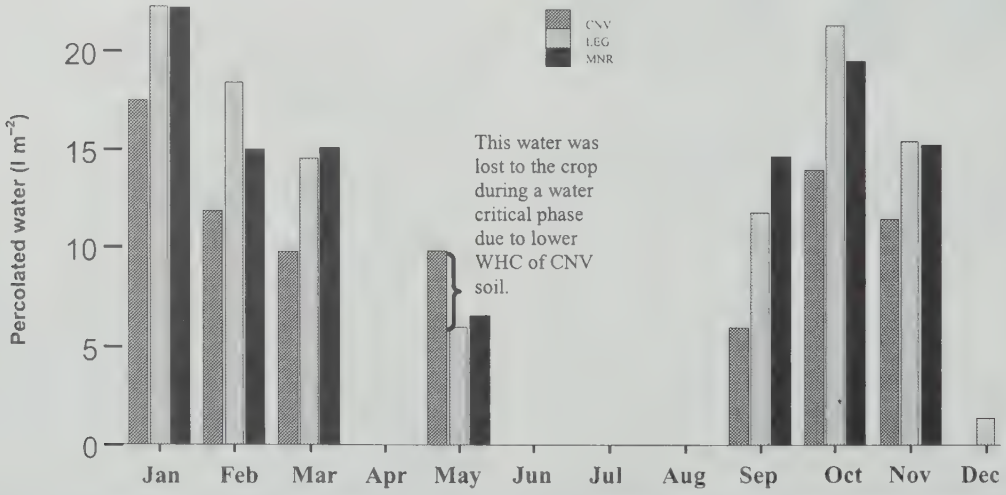


**Figure 9. Monthly percolated water harvested from three cropping systems in 1999 in the Rodale Farming Systems Trial. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic; WHC, water holding capacity**

plots, for the only time in 1999, had more percolated water than the other treatments, indicating that in the LEG and MNR plots more water was retained in the soil for crop use during a time when water was limiting. Over a 5-year period, the LEG and MNR systems captured 16% and 25% more water than the CNV system, respectively (Fig. 8). The MNR plots captured significantly more water than the LEG system.

## Conclusions

Evidence is presented that organic crop systems perform better than conventionally managed crop systems during climate extremes, in this case for both drought and excessive rainfall. In the 21-year Rodale Farming Systems Trial, in which two organic and a conventional crop rotation were compared, the organic crop systems performed significantly better in 4 out of 5 years of moderate drought. In the severe drought year of 1999, three out of the four crop comparisons (LEG soybean, MNR soybean and MNR maize) resulted in significantly better yields in the organic systems than the conventional. The LEG maize treatment yielded significantly less than the CNV due to weed pressure, demonstrating that skill in managing weeds is an important part of organic farming. Evidence indicates that the better water holding capacity of organically managed soils is a likely mechanism for better yields during water deficits. Water harvest, important for groundwater recharge, was significantly better in the organic systems in both the severe drought year and over a 5-year period. Organic crop management techniques will be a valuable resource in an era of climatic variability, providing soil and crop characteristics that can better buffer environmental extremes.

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# Growing out of the niche – can organic agriculture keep its promises? A study of two Austrian cases

Rebecka Milestad and Sonja Hadatsch

Abstract. *The expansion of organic farming has taken off in the European Union and particularly in Austria, where 9% of farmland is certified organic. The main reasons for this development are subsidies and cooperation with supermarket chains. In Austria, many organic farms are located in the mountainous areas, while lowlands with arable cropping have fewer organic farms than the national average. Exploring two regions as case studies, this paper investigates whether the organic farming movement can keep its promises of environmental safety, economic viability and social justice. There is a high level of environmental concern among those who practice organic farming, but local differences are large. It is the individual farmer who determines whether environmental issues beyond the official organic regulations are considered. The economic situation for organic farms is positive due to the financial support from the government and cooperation with supermarket chains, but processing and marketing operations are still lacking for organic products. Regarding social justice, organic farming enjoys a high esteem among consumers, but relations and cooperation between organic and conventional farm sectors is poor. We conclude that it is crucial for the organic movement to focus on qualitative issues rather than quantitative expansion for further sound development of organic farming in Austria.*

Key words: organic farming, Austria, market niche, sustainable development, environment, economic viability, social aspects

## Introduction

Organic farming is often described and promoted as environmentally safe, economically viable and socially just agricultural production, i.e., sustainable agriculture (Lampkin, 1990). Organic farming is also considered a positive force for the viability of rural areas (Lyson and Green, 1999; Pugliese, 2001). The rapid expansion of organic agriculture, increasing subsidies from the European Union (EU), and the introduction of organic products in supermarkets have changed the conditions for organic farming in Europe considerably over the past 10 years. In Austria, conversion to organic farming is a lucrative option for many farmers. The expansion of organic farming is largely a result of increased environmental awareness among consumers and producers, subsidies, and the cooperation with large-scale processors and marketers, such as supermarket chains (Freyer et al., 2001; Vogl and Hess, 1999). The aim of the Action Plan for organic farming of the Austrian Ministry of Agriculture, 2001 and 2002, was to increase certified organic arable land by 50% over the next 5 years, and to keep Austria at the forefront of organic farming in Europe (BMLFUW, 2001c).

In Austria, organic farming received financial support at the regional and national level throughout the 1990s. Organic farming was first supported regionally in 1989, and a national subsidy was introduced in the 1990s (Lampkin et al., 1999; Vogl and Hess, 1999). Since Austria joined the EU in 1995, additional support for organic farming has been granted following the European Council Regulation 2078/92 (Le Guillou and Scharpé, 2000). When supermarket chains entered the organic market in the mid nineties the market expanded rapidly (Freyer et al., 2001; Groier, 1998, 1999; Vogl and Hess, 1999). Supermarkets are now the dominant sales channel for organic produce (Michelsen et al., 1999). The number of organic farms increased from 1539 in 1990 to 8563 in 1993, 19,433 in 1996, and reached a peak in 1998 of 20,316 farms (Freyer et al., 2001). Recently, development has been more moderate and the number of organic farms has decreased somewhat, to 18,433 farms in 2001 (BMLFUW, 2001a, b; Kirner and Schneeberger, 2002; Kirner et al., 2002). The main reduction in numbers of organic farms has taken place in alpine areas, while the number of lowland organic farms has risen somewhat (Kirner and Schneeberger, 2002; Kirner et al., 2002). Michelsen et al. (2001) point out that

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in 1995, before the Austrian Agri-environmental Program was launched, 22,875 holdings were registered for organic farming. However, many of these farms transferred to other agri-environmental measures during that same year and no longer appear in the official statistics. In 2001, 9.1% of Austrian farms were organic, corresponding to 10.6% of farmland; alpine summer pastures are not included (Kirner and Schneeberger, 2002). Almost 50% of organic farms are situated in high alpine areas, more than 90% in less-favored areas, most of which are in mountainous areas (Groier, 1998). The steeper the slopes and the smaller the farms, the higher the percentage of organic farms (Eder et al., 2001).

There are 11 organic farming associations in Austria; all organized under two umbrella associations. However, one-third of organic farmers do not belong to any association (Freyer et al., 2001). Thus, two major paths of development can be discerned. One faction aims to continue to market products directly to consumers or to specialized food shops, and views the whole conventional food system with skepticism. The other group is characterized by an openness towards supermarkets and conventional food processors in their efforts to enlarge the organic market and provide organic food to a large segment of consumers (Vogl and Hess, 1999).

Several of the aims of organic farming concern environmental issues, such as enhancing biological cycles within the farming system, not using fertilizers or chemical pesticides, and minimizing pollution (IFOAM, 2002). Studies show that organic management of farms has positive effects on soil fertility (Mäder et al., 2002), soil organic matter (Lindenthal et al., 1993) and the ability of the soil to hold soluble nitrate (Friedel et al., 1997). Drake and Björklund (2001) compared four European studies on the environmental impacts of organic farming and concluded that organic farming confers less detrimental impacts on the environment than does conventional agriculture (see Hansen et al., 1999; Morris et al., 2001; Stolze et al., 2000; Woese et al., 1997).

Currently in the EU, financial support is granted for organic farming, but at varying levels in different EU countries. In the Austrian Agri-environmental Program, relaunched in 2000, the measure 'organic farming' generates between 96 and 799€ $ha^{-1}$ in subsidies each year, depending on the kind of production (AMA, 2002; BMLFUW, 2000). This support is both an encouragement to convert to organic production and a compensation for the lower yields in organic farming (Lampkin et al., 1999). In addition, organic products normally receive higher prices, varying with the products in question.

According to the International Federation of Organic Agriculture Movements (IFOAM), organic farming is also about the 'progress toward an entire production, processing and distribution chain that is both socially just and ecologically responsible' and allows 'all involved in organic production and processing . . . an adequate return . . . from their work' (IFOAM, 2002). The social dimension has been important since the early days of the organic movement, when it established itself as an alternative way of life and farming (Conford, 2001; Vogt, 2000). The aims of the IFOAM consider the wider social and ecological impacts of farming. Everyone involved in organic farming is entitled to a quality of life that meets their basic needs while giving a sense of work satisfaction (IFOAM, 2002). Browne et al. (2000) found potential for ethical production considerations in organic farming, but the regulatory framework needs to be amended since no social factors are currently included. Organic farmers have pioneered many recent initiatives for a just food system, such as farmers' markets and Community Supported Agriculture (CSA) (Lyson and Green, 1999).

As organic farming expands in Austria, and possibly even moves out of its niche into the mass market, we question whether organic farming will be able to keep all its promises of economic, social and environmental sustainability. Empirical and literature studies were undertaken in two different Austrian regions to determine whether organic farming was perceived to contribute to higher environmental standards, to be economically viable and to be socially just for organic farmers. First, the two regions are presented along with the methods of data collection. Then results are presented for each case in regards to environmental safety, economic viability and social justice.

## Material and Methods

Two contrasting regional case studies were explored. The first is situated in the productive lowland, large-scale agricultural region of Marchfeld, close to Vienna. The second is the alpine, small-scale, extensive farming area of Sölktäler, a landscape also valued by tourists.

### Marchfeld

Marchfeld is the most important vegetable-producing area in Austria. It covers an area of 1001 $km^2$ and consists of 36 municipalities. In 1995, 2690 farmers farmed 86,701 ha, of which 84% was agricultural land and the remainder was forestry (Hadatsch et al., 2000). More than 75% of all farms have no cattle, but those that do have on average 42 animals, more than double the Austrian average of 20 animals. Less than 2% of the farms in Marchfeld are certified organic farms. The average Marchfeld farm size is 32 ha. Interestingly, organic farms in the Marchfeld are significantly larger, averaging 53 ha (Hadatsch et al., 2000). There are differences between organic and conventional farm production in the Marchfeld. While conventional farms grow vegetables, sugar beet, potatoes, cereals, and wine and fruits, organic farms tend to grow more leguminous crops, animal feed and green manure, and less sugar beet, maize, cereals and rapeseed. They are also more likely to have animals on the farm (BMLFUW, 2001a).

Marchfeld is a sensitive area concerning water conservation, due to intensive farming and its soil structure. The intensive land use leaves little room for ecologically valuable landscape elements and habitats that are not directly productive for agriculture. The main reasons for conversion to organic farming among farmers in Marchfeld are the increasing market demand for organic vegetables and cereals, as well as financial support from the Austrian Agri-environmental Program (Hadatsch et al., 2000). The successful partnership between the largest organic farmers' association (Bio Ernte) and one of the largest supermarket chains in Austria (Billa/Merkur) is a major reason why large farms in Marchfeld have found it financially attractive to convert to organic farming (Hadatsch et al., 2000). The supermarket's processing industry and numerous shops provide these farms with a market for the large quantities they produce.

### Sölktäler

Sölktäler is a mountainous, grassland area and a typical example of an area with a high density of organic farms in Austria. This case-study site was chosen to represent smaller farms. Sölktäler consists of three municipalities covering 277 $km^2$, with 103 farm holdings. The average farm includes 17 ha of agricultural land and 21 ha of forest (Statistik Austria, 2001). Approximately a quarter of all agricultural land is alpine pasture, and the remainder is mainly meadows. There is no arable land in Sölktäler. However, until the 1960s farmers grew potatoes and some cereals in the valleys (Loseries-Leick, 2000). Approximately 50% of all farms in the three municipalities are certified as organic. Milk and meat production are the dominant enterprises. Traditional farming in Sölktäler, as in most similar areas in the Alps, is ecologically benign. Mechanization can only partly substitute for human labor, since steep slopes and the small scale of farm operations do not allow full mechanization. The Alps are an ecologically sensitive area, as overly intensive or extensive use of the land can cause landslides, avalanches or undesired forestation (Bätzing, 1991, 1997).

### Data collection

To display a rich picture of the situation of organic farming in Austria is one aim of this paper. In both regions, qualitative interviews (Denzin and Lincoln, 2000; Kvale, 1996) were carried out with farmers and other participants in the agricultural sector.

In Marchfeld, semi-structured expert interviews were carried out with farmers and other stakeholders from organic farming (3), organic marketing (1) and conventional and integrated agriculture (4), and with a water conservation agent (total $n=9$). Integrated agriculture is advocated in this region by the organization '*pro Landschaft*' and is mainly concerned with decreasing the use of pesticides and the protection of ecologically valuable landscape elements and habitats for wildlife. The parts of the semi-structured interviews relevant for this paper concerned how the interviewees considered the perspectives and experiences of organic farming to be among different groups of farmers and other participants. The interview checklist also focused on the interviewees' assessment of the environmental, economic and social performance of organic farming and the future of agriculture in the region. The complete interview checklists can be found in Hadatsch et al. (2000).

Specific economic and ecological assessments were also carried out for the Marchfeld region (Hadatsch et al., 2000). The economic assessment was carried out in respect to profitability of organic farms. The environmental assessment compared ecological performance of organic and conventional farms in respect to so-called '*Ökopunkte*' or 'ecological points', an environmental assessment model developed and used in the province of Lower Austria. *Ökopunkte* considers the entire farm, as well as the surrounding landscape (for details, see Hadatsch et al., 2000).

In Sölktäler, individual interviews with 13 farmers, an agricultural advisor, a representative from a village development group, and a manager of a natural conservation area (total $n=16$) were performed. Then three group interviews with agricultural teachers and pupils and three workshops with farmers and agricultural school pupils were carried out. The study in Sölktäler was part of a larger research project in the region Liezen, of which Sölktäler is a part. Thus, some results from Liezen are generalized for Sölktäler as well. This is mainly the case for the economic and environmental assessments (Bartel et al., 2002).

The checklist for the semi-structured interviews in Sölktäler concerned farmers' perspectives on organic farming, the future of agriculture in the region, and what constitutes sustainable agriculture in Sölktäler. In the workshops, organic farming was assessed in respect to its ability to fulfill criteria for sustainable agriculture—which was determined by the workshop participants themselves. The results are presented in Bartel et al. (2002).

The two interview studies presented in this paper are of a qualitative nature. That is, no statistical analyses have been carried out on the interview data and thus no generalizations of the population of farmers are made. The interviews were transcribed and subsequently analyzed and interpreted thematically (Froschauer and Lueger, 1992; Miles and Huberman, 1994). The strength of qualitative case studies is that they can make visible the complexity of contemporary phenomena (Yin, 1994).

## Results

The results from Sölktäler and Marchfeld concerning environmental safety, economic viability and social justice in organic farming are presented below.

### Organic farming and environmental safety

**Marchfeld.** When comparing *Ökopunkte* between organic farms and conventional farms with respect to crop rotation, ground cover, manure intensity, pesticide use and manure management, organic farms scored higher in most instances (Hadatsch et al., 2000). However, some of the organic farms had fewer ecologically valuable landscape elements than some of the conventional farms. In the *Ökopunkte* assessment, organic farms did not score better than conventional farms concerning ecologically valuable landscape elements. It was not a result of production system, but it varied between farms, depending on the interest of the farmer. Among organic farmers, those with smaller farms were more willing to do extra work, while the large farm owners were not. There was no consensus among the interviewees that organic farming has a positive influence on the environment in Marchfeld. Not surprisingly, farmers and other stakeholders from the organic movement were more inclined to believe in the positive environmental effects than farmers and other participants involved in conventional and integrated agriculture. Stakeholders from conventional and integrated agriculture were not convinced that organic farming could manage their nitrogen budget better than conventional farms, i.e., prevent nitrates from leaching into the groundwater. Further, they criticized organic farmers for not protecting or managing ecologically valuable landscape elements or habitats where endangered species dwell.

Among the interviewees from organic farming, the main concern was not whether organic farming managed the environment better than conventional agriculture, of which they were convinced, but rather the level of ecological knowledge among large-scale, recently converted organic farmers in Marchfeld. The interviewees worried that most of these farmers were not familiar with the aims and goals of organic farming, but only had rudimentary knowledge of organic farming and ecological processes.

**Sölktäler.** In this region, organic farming was considered a continuation of traditional practices. Subsequently, very few differences are seen between conventional and organic alpine farming.

While the nitrate surplus was slightly higher for conventional farms in Liezen, no differences were found between organic and conventional farms in respect to potassium or phosphate levels (Bartel et al., 2002; Gigler, 2001). Among the interviewed farmers, organic farming was not perceived to manage site-specific environmental problems such as physical degradation of landscape, e.g., when heavy cattle tread on sensitive land. Farmers mentioned two main reasons for this. First, traditional farming is labor intensive and most farms in Sölktäler do not have access to enough labor to manage meadows and pastures as they may wish. Thus, sufficient management is lacking in organic and conventional farms alike, with degradation as a consequence. Secondly, issues of interest and motivation are important determinants as to whether such work is done well. There were hardly any differences in perspectives between conventional and organic farmers in Sölktäler. Most of the interviewees agreed that all farms could certify as organic if they wanted to. 'We are all more or less organic' was a common comment.

### Organic farming and economic viability

**Marchfeld.** Under current market and subsidy conditions, conversion to organic farming is profitable for the average Marchfeld farm (Hadatsch et al., 2000). Those involved in organic farming mentioned several specific challenges for large organic farms. In Marchfeld, most farms produce cereals or vegetables and have no animal production and thus no animal manure. To determine a crop rotation scheme that takes this into account is a crucial, new challenge for organic farmers, since the vast majority of Austrian organic farms engage in animal husbandry. Another challenge is the increased need for hired labor on large organic vegetable farms. Since no pesticides are allowed, farmers rely on manual labor for weeding. Labor intensity and costs are considerably higher for organic vegetable producers than for conventional farmers in Marchfeld. Actual costs differ between crops, with onions as the most costly crop. Despite this, organic producers still earn more per family work hour than their conventional colleagues (Hadatsch et al., 2000).

While the partnership with the supermarket chain Billa/Merkur has enabled large organic farms to find a market for their products, many farmers are disappointed with the terms offered by the supermarket. Farmers feel they are maneuvered against each other and some even claim that Billa/Merkur has broken contracts without compensation. According to the interviewees from conventional farming, the behavior of Billa/Merkur towards organic farmers in Marchfeld makes them reluctant to consider conversion, despite the market potential (Hadatsch et al., 2000).

Despite the low number of organic farms in Marchfeld, two groups of organic farms can be discerned. The small farms, which have often been certified organic for some time, and the larger farms, more recently certified. While large organic farms in Marchfeld concentrate on bulk products such as cereals and vegetables, small organic farms typically have to find niche markets, and/or market their products directly to consumers, in order to be profitable. The interviewees speculated that only large farms will be successful if prices are reduced. Thus, the interviewed experts feared that, as a result, the level of competition within the organic market will become similar to that in conventional farming (Hadatsch et al., 2000).

**Sölktäler.** Conversion to organic farming enables Sölktäler farms to remain economically viable—especially if no investments are needed in order to convert. Farmers are reluctant to make investments necessary to comply with the organic regulations for animal husbandry. An uncertainty for Sölktäler organic farmers involves cowsheds. Most farmers still do not have cowsheds that comply with

the organic guidelines, where the tethering of cows is not permitted. However, alpine farmers are exempted from this rule until 2010, and even longer if they are considered to be 'small farms' (cf. Kirner and Schneeberger, 2002). The definition of a small farm is up to each EU member state to decide, and among the Sölktäler farmers there was uncertainty about this definition.

A large part of organically produced milk is marketed as conventional since there is not enough demand and/or there are not enough organic processors and marketing operations. Organic and conventional milk are both processed in the regional dairy, Ennstal Milch, which is a subcontractor to national and international brands of dairy products. The region also lacks sufficient facilities for organic meat processing. This is an incentive for organic farmers to process on farm and to market their products in farmers' markets, to restaurants and to tourists. In addition, a group of organic and conventional farmers has set up a meat marketing facility in one of the valleys.

Farm revenues are normally insufficient to cover the expenses of the Sölktäler farm household, and thus additional income is necessary. This is true for farms in general and for organic farms in particular, since their production output is smaller. Pluriactivity, i.e., a multitude of income sources both on and off farm (Kinsella et al., 2000; Mackinnon et al., 1991) is common and traditional in Sölktäler. Additional on-farm activities are direct sales to tourists and neighbors, bed-and-breakfast enterprises or forestry activities. Off-farm work can include odd jobs, forestry, ski instruction during the winter season, or even full-time work outside of farming but within the region.

## Organic farming and social justice

**Marchfeld.** Communication between conventional and organic farmers in the Marchfeld was described as poor by the interviewees. This is considered problematic if organic farming is to develop further and to enjoy a higher level of acceptance among conventional farmers. According to the interviewees from conventional and integrated agriculture in Marchfeld, these farmers evaluate their organic colleagues by their economic and production performance. They belittle ecological and ethical concerns as romanticism (Hadatsch et al., 2000).

The increased need for hired labor on large organic farms is considered to be a social strain on the farm family, especially for women, who are normally responsible for the organization of, and catering for, hired labor. Thus female farmers must work more hours on an organic farm than on a conventional farm in the Marchfeld. Generally, extra labor is hired seasonally and normally from neighboring countries (e.g., Slovakia and Hungary), and working conditions and wages are not the same as Austrian workers' requirements.

**Sölktäler.** In Sölktäler, organic farmers were generally considered more innovative than conventional farmers. Two explanations were given for this. First, organic farmers have to find more sources of income in order to make ends meet. They have to 'do many small jobs'. Secondly, organic farmers are often active members of the community and initiate projects such as the monthly farmer's market. Since many farmers offer bed-and-breakfast accommodations to tourists, this provides an additional opportunity to sell products. Organic farmers have also discovered that their products are well received among the urban population.

However, to process farm products is labor intensive. There is a disproportionate increase in labor for female farmers since they are traditionally responsible for such activities. The lack of appropriate processing and marketing structures beyond the farm gate complicates life further for organic farmers in Sölktäler. As already mentioned, not all organically produced milk and meat is marketed as such. Yet, all organic milk receives a premium price from the dairy. In the payments for organic milk, a distinction is made between ordinary organic farmers and 'project farmers' (cf. Kirner and Schneeberger, 2002). Project farmers have to fulfill stricter regulations than EC Regulation 2092/91, which is the minimum requirement for organic certification in the EU. While ordinary certified organic farmers are allowed to use a small portion of conventional feed, project farmers can only use organic feed. The project farmers' milk is only sold as organic. This differential treatment of organic farmers is taken as proof by some that both organic and conventional processing industries treat farmers in the same exploitative way.

## Discussion

In this section, the environmental, economic and social issues in organic farming are discussed in relation to the two cases described above, and in relation to the growth of the organic sector in Austria and Europe.

Organic farming in Marchfeld could be considered a step in the right direction towards reducing environmental loading by the agricultural system, since organic regulations do not allow use of pesticides, fertilizers or high stocking rates of animals (Bio Ernte, 2001; IFOAM, 2002). However, there is criticism of organic farming in respect to nutrient leaching, both in Marchfeld and in the literature. Results of a number of studies differ as to levels of nutrient leaching from organic farms (see Stolze et al., 2000, pp. 45–50). The integrated agriculture movement, *pro Landschaft*, also emphasizes management and protection of ecologically valuable landscape elements and habitats. Therefore, awareness of such issues is high, and organic farming is consequently criticized for not providing special protection.

Studies in areas similar to Sölktäler have shown that the intensity of mowing and land use has a greater influence on biodiversity than whether farm production is organic or conventional (cf. Schiller, 2000). This supports the notion among most interviewees in Sölktäler that the differences

between organic and conventional management are small, and that other aspects can be equally important.

Economic motives for a conversion to organic farming seem to be important. Among cash-crop farmers in lowland areas similar to Marchfeld, expensive investments and external inputs, and small price differences between organic and conventional products, were common concerns regarding a conversion to organic farming (Schneeberger et al., 2002b). Issues such as the higher level of dependence on natural variations and weather, and the limited possibilities for corrective alternatives compared to conventional agriculture, were also major concerns. Other constraints rated as important were increased labor requirements and bureaucracy, and concern about farmers' ability to secure price premiums.

Half of the farms that reverted back to conventional farming in Austria during 1999 and 2000 were milk producers (Kirner and Schneeberger, 2002). While Kirner and Schneeberger (2002) claim that there are additional costs for organic milk production, mainly due to feed prices and cowshed buildings, Schneeberger et al. (2002a) considered income in organic farms to be generally higher in areas such as Sölktäler. Still, economic problems are considered an important reason for reversion to conventional farming. Another reason was retirement without a farm successor (Kirner and Schneeberger, 1999b). In addition to the somewhat higher prices paid for organic milk, organic farms get 392€ $ha^{-1}$ from subsidies, while conventional farms can obtain 211€ $ha^{-1}$ of subsidies (Schneeberger et al., 2002a). In the Austrian Agri-environmental Program there are 25 levels of compliance—organic farming receives the highest level of subsidy. Many farmers in alpine areas such as Sölktäler settle at the level of 'non-usage of pesticides and artificial fertilizers', however. This allows farmers to maintain stocking intensity in the cowsheds (Kirner and Schneeberger, 1999a). These farms tend to be smaller than certified organic farms, to be full-time farms to a lesser degree, and to be less diversified. Generally, however, there are few differences between this group of farms and organic farms (Kirner and Schneeberger, 1999b).

If organic farming continues to increase, it will grow out of its niche and become a mainstream market in Austria. This will have implications both for the economic and social realities in organic farming. According to Bahner (2000), the higher prices presently obtained by organic farm products would decrease, unless demand increases. Also, as the number of organic growers increases, so may competition. If organic farming grows out of its niche, viable strategies for all organic farmers need to be found. If not, we may see the specialization and enlargement of farms, increased competition between farmers, decreasing prices, and the use of increased external inputs in organic farming, just as in conventional agriculture (Tilman et al., 2002). This trend is already being seen in a number of areas where organic farming is on the increase (Allen and Kovach, 2000; DeLind, 2000; Tovey, 1997). This reasoning is part of the so-called 'conventionalization argument' (Buck et al., 1997; Hall and Mogyorody, 2001; Milestad and Darnhofer, 2003; Tovey, 1997). Although organic farming started out as a social movement, it is now institutionalized in regulatory frameworks, supported by policy and highly integrated into agri-business (Michelsen et al., 2001). In the case of Marchfeld, the conventionalization argument seems to apply to the strong involvement of conventional agri-business.

In the Sölktäler case, organics could be thought of as mainstream since half of all farms are already certified organic. Since most farmers have not had to make any management changes, organic and conventional farms in Sölktäler tend to be similar. Despite the high degree of direct sales and on-farm processing, all farmers in Sölktäler are dependent on the regional dairy. Even if the dairy is a farmers' cooperative, there is not much that organic farmers can do if the dairy decides to pay a smaller premium for organic milk.

In many European countries, national targets for organic farmland have been set, e.g., 20% by 2005 in Sweden, 20% by 2010 in Germany, 12% by 2003 in Denmark, and action plans have been developed accordingly, both at the national and at EU level (Lampkin, 2002). Austria states its wish to maintain the highest percentage of organic farms in Europe (BMLFUW, 2001c). The Austrian Action Plan suggests increased financial support to organic farming relative to conventional farming, for example support for investments in farm buildings. Further, the Ministry concentrates on education in organic farming, strengthened research and marketing channels, as well as the launch of public information campaigns. These measures are a step in the right direction, as they address many of the reasons that conventional farmers in Marchfeld and Sölktäler mentioned for not converting to organic farming, even though Sölktäler farmers already managed their farms similarly to organic farmers: expensive investment in cowsheds, more expensive inputs, more bureaucracy, and small price differences between conventional and organic products (Kirner and Schneeberger, 1999b). Interestingly, the authors found that one-third of farmers practicing 'non-usage of pesticides and artificial fertilizers' would consider a conversion to organic farming if subsidies were higher. Hence, policymakers can only influence directly a small fraction of all factors conducive for more farmers to certify as organic.

## Conclusion

Austria has experienced a rapid expansion of organic farming since the 1990s. Farmers receive significant economic incentives to convert their farms, and supermarkets have taken advantage of the market potential for organic products. The two cases show that organic farming is practiced under diverse conditions, in different settings. In Marchfeld, several large organic farms try to survive in the market by cooperating with a dominant supermarket

chain. In Sölktäler, many small producers deliver to a single regional dairy, and direct sales are also important.

Indeed, many of the results from the case studies seem to support the idea that organic farming fosters ecological, economical and social sustainability. In Marchfeld, organic farming reduces the negative environmental impacts of agriculture and can give growers a higher income. In Sölktäler, organic farming helps farmers sustain traditional farming, while remaining economically viable and enjoying support among consumers. However, there are problems. Current organic practices do not seem to cover all ecological aspects of the farm, but depend partly on the interests and motivation of the individual farmer. Moreover, organic farming depends on conventional structures for processing, sales and marketing—organic farmers tend to be subject to the same market forces and pressures as conventional farmers.

Growth of the organic sector is an important policy goal in Austria and other EU countries. However, it is important not to neglect the qualitative aspects of organic farming during a phase of rapid growth.

In order to look beyond quantitative expansion and focus on the qualitative content of organic farming, attention to ecological, economic and social issues is necessary. A sustainable development of agriculture needs to go hand in hand with a similar development in society as a whole. In the current situation, it seems that if organic farming is to fulfill its promise of environmental safety, it has to be supported by either a genuine interest from individual farmers or by strong economic incentives from governmental subsidies for desired practices, and/or fees for undesired practices. If organic farming is to fulfill its promise of economic viability, it must cooperate in the market sector, or with government support, to compensate economically for the extra labor input. If this does not happen, then organic production will develop as large-scale conventional agriculture has, where human effort is replaced by fossil energy, machinery and other inputs. Finally, if organic farming is to fulfill its promise of social justice, it needs to enter into a dialogue with the society surrounding it; for example, expand consumer–producer relationships.

New methods and channels of communication and cooperation are needed within the organic farming movement, with consumers, and between organic and conventional farmers (cf. Schneeberger et al., 2002b). Social and ecological aspects of sustainability, beyond those currently available, need to be stressed in agricultural education and advisory services (cf. Lampkin et al., 1999). Bahner (2000) even goes so far as to argue for the abolishment of subsidies to farmers, and for a focus on self-reliance and participatory development. This is not likely to be an option in the near future. Nevertheless, it will be a challenge to rationalize these contrasting views and to design a comprehensive strategy for Austria to meet its stated national goals.

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# Agronomic performance and quality of spring wheat and soybean cultivars under organic culture

H.G. Nass, J.A. Ivany and J.A. MacLeod

Abstract. *Spring milling wheat (*Triticum aestivum *L. em. Thell) and soybean (*Glycine max *L.) cultivars were managed to International Organic Certification Standards on two organically certified farms to evaluate two physical weed control methods, cultivar performance and quality. Nutrients were supplied as manure and compost. There was no difference (P<0.05) between flaming plus fingerweeding versus fingerweeding twice, 10 days apart, on weed control, yield, and protein in both crops. The spring wheat cultivar, AC Barrie, may be particularly well suited to production under an organic system, as indicated by its superior performance to AC Walton at the Springfield site in 2000, when growth conditions were favorable. A severe drought in 2001 limited the mineralization of soil and manure nitrogen, with the result that all spring wheat cultivars at the Springfield site did not make 13.5% grain protein, required to meet milling quality criteria. Also, in 2001 at both sites, soybean yields were reduced by 50% compared to 2000 because of reduced moisture availability and weed competition. Delays in field operations, lack of sufficient soil moisture and reduced mineralization of manure during the 2001 growing season were major factors in influencing crop production, especially at Springfield.*

Key words: spring wheat, *Triticum aestivum*, soybean, *Glycine max*, protein, nitrogen, organic, weed populations

## Introduction

In Canada's Maritime provinces, concern has increased about the use of agricultural pesticides and high rates of chemical fertilizer and their detection in surface- and groundwater. Organic farming is a production system which largely excludes the use of synthetic fertilizers, pesticides, growth regulators and livestock feed additives (Cacek and Langer, 1986). Pang and Letey (2000) suggested that conversion from conventional to organic farming may be a means to reduce groundwater degradation. Organic rotations may produce crop yields comparable to those of conventional rotations. However, higher-value organic crops may occur less frequently in the rotation and require more labor and management compared to conventional systems (Hanson et al., 1997).

A limited amount of research has been conducted in Canada's Maritime provinces to guide farmers who wish to farm organically. Spring wheat cultivars that have been grown under organic culture are often heritage cultivars. Furthermore, cultivars that produce well in organic systems may have different yield rankings in conventional systems (Lampkin, 1990; Poutala et al., 1993; Stöppler, 1988). In organic systems, competitiveness with weeds, rooting ability and soil management environments differ from those of conventional systems. Stöppler (1988) found that high yields in organic systems are closely related to high above-ground biomass and high straw yields, and that these factors are associated with greater root penetration and development, which is important for the nutrition of the plant and for anchorage where mechanical weed control is used. In organic systems, short-strawed wheat cultivars may be at a disadvantage compared to taller cultivars because they provide a more open canopy, allowing weeds to compete more effectively (Lampkin, 1990).

Walker and Smith (1990, 1991, 1992) and Walker et al. (1999) conducted trials to identify spring wheat cultivars that would be suited best for organic production. Grain yields of 15 spring wheat cultivars grown at four certified organic sites in New Brunswick in 1998–1999 ranged from 1.7 to 2.4 t $ha^{-1}$, which are similar to those produced under conventional systems (Walker et al., 1999). Grain protein ranged from 12.9 to 14.9%, depending on the cultivar. Entz et al. (2001) surveyed 14 organic farms in Manitoba and Saskatchewan and found that organic grain yields averaged from one-half to almost double conventional yields. However, Munn et al. (1998) reported that in long-term

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studies, yield of organic crops seldom return to the levels achieved with conventional crops produced with fertilizer and pesticides.

Samuel and Guest (1990) found a greater range and number of weeds in organic crops compared with conventional fields in an intensive arable rotation. McCloskey et al. (1998) found differences in response of weeds to tillage and weed control regimes, with minimum-cultivated plots becoming dominated by high densities of specific weeds. Andres and Clement (1990) suggested that in a specific crop (spring wheat) being grown, a certain number of plants of some other species, for example corn spurry (*Spergula arvensis* L.), can be accepted, while others, such as wild oats (*Avena fatua* L.), should be excluded.

Some Maritime farmers are in the process of changing, or have changed completely, to organic production systems. Further research is required to identify management factors needed to achieve acceptable organic grain yields and quality on a consistent basis. Trials conducted using organic systems by Walker and Smith (1990, 1991, 1992) and Walker et al. (1999) did not determine whether differences in cultivar performance occurred in response to weeds. Therefore, the objectives of this study were: (1) to examine the performance and quality of selected cultivars of spring milling wheat and soybeans in an organic production system; and (2) to determine the effect of two methods of weed control on grain yield, weed density and biomass.

## Materials and Methods

Field experiments were conducted in 2000 and 2001 on two organically certified (Organic Crop Improvement Association International, Inc., 1999) farms, located in Springfield and Cherry Hill, Prince Edward Island, Canada. Crop rotations at Cherry Hill were: (1) fall rye (*Secale cereale* L.) (1999), spring wheat plots (2000) and soybean plots (2001); and (2) fall rye (1999), soybeans plots (2000) and spring wheat plots (2001). At Springfield the rotations were (1) red clover (*Trifolium pratense* L.) (1999), spring wheat plots (2000) and soybean plots (2001); and (2) red clover (1999), potatoes (*Solanum tuberosum* L.) (2000) and spring wheat plots (2001). The results of soil test analysis before the crops were planted in 2000 are given in Table 1. In the spring, the fields were disked and harrowed. At Springfield, cattle manure was applied at 22 t $ha^{-1}$ to provide 140 kg N $ha^{-1}$, 55 kg $P_2O_5$ $ha^{-1}$ and 105 kg $K_2O$ $ha^{-1}$. At Cherry Hill, compost was applied at 20 t $ha^{-1}$ to provide 88 kg N $ha^{-1}$, 86 kg $P_2O_5$ $ha^{-1}$ and 82 kg $K_2O$ $ha^{-1}$. These nutrient sources were applied 1 week before seeding each year at both sites. Both crops were planted into a stale seedbed 5 days after seedbed preparation. Plots were 25 m × 3.5 m and 20 m × 3.5 m at Cherry Hill and Springfield, respectively.

Generally, Maritime organic farmers produce spring wheat cultivars with milling quality to meet the needs of the organic milling wheat market. For this reason, spring wheat cultivars with milling quality were selected. Commonly grown cultivars of spring wheat (Atlantic Advisory Committee on Field Crops, 2002) and soybean (Prince Edward Island Department of Agriculture and Forestry, 2002) in the Maritimes were chosen so that the results could be related to commercial practice. Spring wheat cultivars AC Barrie, AC Walton and Glenlea were seeded with a Hege cereal planter at 450 seeds $m^{-2}$, in plots 20 rows wide and 18 cm between rows. Soybean cultivars OAC Vision, Alta and Ugo were seeded with a Juko seeder at 90 seeds $m^{-2}$, in plots 10 rows wide and 36 cm between rows. The Alta seed had an unexpected field germination of only 70% and was replaced by AC Proteina in 2001.

Plot sizes were quite large so as to accommodate the commercial machinery used in this study and the donated fields by organic farmers were limited in size, making only two weed control treatments possible. The estimated weed pressure at Springfield for 2000 was considered too great to grow soybean. The weed control treatments were as follows: (1) flaming about 10 days after seedbed preparation when emerged weeds were in the cotyledon stage, and fingerweeding about 10 days after flaming using a Lely fingerweeder, when newly emerged weeds were in the cotyledon stage; and (2) fingerweeding about 10 days after seedbed preparation followed by a second fingerweeding about 10 days later, when newly emerged weeds were in the cotyledon stage. Flaming was conducted when wheat plants were either not emerged or less than 10% of shoots were 1–2 cm above ground. Soybean plants were not emerged at the time of flaming. Flaming was conducted with a tractor-mounted flamer fueled by propane, which was released at a pressure of 275 kPa. The flaming heads (16 cm wide, 45 cm apart from the center of the flaming head, 20 cm above ground) were mounted in front of the tractor, which traveled at a speed of 3.2 km $h^{-1}$ and developed a temperature of 70–80°C at plant level. The 3.7 m wide fingerweeder (Lely Industries N.V., Maasland, Holland, Type Nr. 35103 0050), a three-point hitch-mounted harrow with four rows of spring steel wire tines, 15 cm apart and 40 cm long, was pulled by a tractor at a speed of 15 km $h^{-1}$, with tines set at a depth of 2–3 cm.

While it would have been useful to obtain weed counts prior to application of the weed control treatment, this was not done because the treatments were applied prior to all weeds having emerged. The first weed control treatment was done as a 'blind tillage' operation and was planned to control emerged, as well as germinated but not emerged, weeds at the 'white root stage', so as to obtain maximum weed control. Weed counts and biomass were taken twice, 21 days after the last fingerweeding and prior to harvest. Plants were harvested at soil level in an area 0.5 m × 0.5 m, weed species were separated, fresh weight was determined and samples dried at 70°C for 72 h, at which time dry weight was determined. Crops were mechanically harvested from 31.1 $m^2$ and 24.9 $m^2$ areas at Cherry Hill and Springfield, respectively, with a Hege plot combine. Test

weight was determined by allowing a random grain sample from each spring wheat plot to fall from a funnel apparatus into a 1 litre volumetric cup, leveling off with a metal rod and weighing on a scale. Kernel weight was determined by counting out 1000 kernels with a seed counter (Old Mill Company, Savage, Illinois; Model 850–2), weighing the sample on a scale and calculating the average weight per kernel. Protein was determined with an Infratec grain analyzer (Perstorp Analytical, Silver Spring, MD, USA) on a 500 g sample of whole grain.

Additional plot information for both sites is given in Table 1. Mean monthly air temperature and precipitation are given in Table 2 and soil temperature in Table 3 for the 2000 and 2001 growing seasons. Long-term mean monthly air temperature and total precipitation are given in Table 2.

The experimental design was a split plot with four replications, cultivars being the main plots and weed control treatments the subplots. This design was chosen because it provided a more sensitive evaluation of weed control treatment effects than if weed control treatments had been the main effect. The statistical programming language, Genstat 5, release 3 (Genstat 5 Committee, 1993) was used to conduct an ANOVA across the two sites for each crop. In the case of soybean, only Ugo and AC Vision were included in the analysis across sites. Alta and AC Proteina data were analyzed within individual years. Analysis of transformed data $[\log_{10}(x+1)]$ of total weed number $m^{-2}$ and total weed dry weight $m^{-2}$ was not different from non-transformed data; therefore, actual weed number and dry weights are presented.

## Results and Discussion

### Spring wheat

Grain yield, protein, test weight and kernel weight were not affected by weed control method (Table 4). Grain yields and protein contents differed between sites and there were interactions for cultivars over sites (Table 4).

Grain yields (2.2–3.7 t $ha^{-1}$ Springfield 2000, and 2.24–3.17 t $ha^{-1}$ Cherry Hill 2001; Fig. 1) were comparable to the 10-year Prince Edward Island provincial average of 3.1 t $ha^{-1}$ (Canada Grains Council, 2002). In 2000, at Springfield, AC Barrie (3.2 t $ha^{-1}$) yielded considerably more than AC Walton (2.67 t $ha^{-1}$). This is in contrast to long-term results from conventional cultivar trials (Atlantic Advisory Committee on Field Crops, 2002) where AC Walton always yields greater than AC Barrie (4.25 t $ha^{-1}$ versus 3.50 t $ha^{-1}$). This supports similar findings of Mengel (1983) that some cultivars perform better in specific organic systems than in conventional systems. Grain yields at Cherry Hill in 2001 (Fig. 1) may have benefitted from the soybean crop grown the previous year in the rotation (Table 1).

The excellent yields obtained at Springfield in 2000 were produced with high fertility, low weed pressure and

**Table 1. Springfield and Cherry Hill site history and plot management information.**

| | Location | | | |
|---|---|---|---|---|
| **Variable** | **Springfield** | | **Cherry Hill** | |
| Soil series | Charlottetown | | Charlottetown | |
| Surface soil texture | fine sandy loam | | sandy loam | |
| Year | 2000 | 2001 | 2000 | 2001 |
| Soil test (spring of 2000) | | | | |
| Organic matter (%) | 3.6 | | 3.9 | |
| pH | 5.7 | | 6.6 | |
| Phosphate ($P_2O_5$) (ppm) | 140 L[1] | | 235 M+[1] | |
| Potash ($K_2O$) (ppm) | 85 M[1] | | 215 H+[1] | |
| Previous crop | | | | |
| Spring wheat | Red clover | Potatoes | Fall rye | Soybeans |
| Soybean | Not planted | Spring wheat | Fall rye | Spring wheat |
| Seedbed preparation | May 17 | May 25 | May 31 | May 17 |
| Planting | 5 days after seedbed preparation | | | |
| Weed sampling and counts | | | | |
| Spring wheat | July 13 | July 19 | July 21 | July 18 |
| | August 16 | August 2 | August 16 | August 1 |
| Soybean | Not planted | July 19 | July 21 | July 18 |
| | | August 14 | August 17 | August 13 |
| Harvest | | | | |
| Spring wheat | September 6 | September 4 | September 15 | August 31 |
| Soybean | Not planted | October 11 | October 26 | September 24 |

[1]L, low; M, medium; M+, high medium; H+, very high based on Prince Edward Island Department of Agriculture fertilizer recommendations.

**Table 2. Monthly long-term, 2000 and 2001 air temperatures and precipitation during the growing season at Harrington, Prince Edward Island.**

| | 2000 | | | | 2001 | | | | Long term | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Daily temperature | | | | Daily temperature | | | | | |
| | Mean (°C) | Max (°C) | Min (°C) | Precip. (mm) | Mean (°C) | Max (°C) | Min (°C) | Precip. (mm) | Mean temp. (°C) | Total precip. (mm) |
| April | 3.6 | 7.2 | 0.5 | 68.5 | 0.7 | 3.9 | –2.4 | 64.8 | 2.7 | 88.3 |
| May | 7.4 | 11.7 | 3.3 | 100.4 | 9.7 | 15.2 | 4.2 | 118.6 | 9.1 | 94.2 |
| June | 15.0 | 19.5 | 10.0 | 61.5 | 15.7 | 20.3 | 11.1 | 62.4 | 14.8 | 87.5 |
| July | 17.5 | 21.5 | 13.5 | 160.8 | 17.9 | 22.0 | 13.8 | 54.5 | 18.7 | 78.5 |
| August | 18.0 | 21.6 | 14.9 | 67.2 | 19.6 | 25.0 | 14.6 | 10.9 | 18.4 | 90.1 |
| September | 13.6 | 17.6 | 10.4 | 71.0 | 15.7 | 20.8 | 10.3 | 27.4 | 13.9 | 91.9 |
| October | 8.8 | 12.5 | 5.7 | 174.0 | 10.5 | 15.3 | 5.8 | 83.6 | 8.6 | 112.4 |

**Table 3. Monthly mean soil temperatures at 10 cm depth at Harrington, Prince Edward Island for 2000 and 2001.**

| | 2000 (°C) | 2001 (°C) |
|---|---|---|
| January | –0.6 | –0.2 |
| February | –1.2 | 0.0 |
| March | –0.1 | 0.1 |
| April | 2.4 | 0.5 |
| May | 7.6 | 9.6 |
| June | 14.7 | 16.0 |
| July | 17.9 | 18.7 |
| August | 18.4 | 20.3 |
| September | 14.4 | 16.6 |
| October | 9.0 | 10.9 |
| November | 5.3 | 4.6 |
| December | –0.1 | 1.7 |

favorable growing conditions. Total weed numbers in spring wheat were about twice as large at Cherry Hill in 2001 compared to 2000, but similar between years at Springfield (Table 5). However, total weed dry weight at Springfield and Cherry Hill was about three and four times larger, respectively, in 2001 compared to 2000, because of a drought during the 2001 growing season (Tables 2 and 3). In 2001 at both Springfield and Cherry Hill, the number of weeds and weed biomass were high and grain yields were much below the 10-year provincial Prince Edward Island average.

Gruber et al. (2000) reported that their organic system was characterized by an increase in diversity and abundance of weeds. Tersbol and Peterson (1999) found that, in general, the effects of harrowing on the control of weed populations were less than those of chemical control. At Springfield in 2000, there were few weeds in a dense, tall spring wheat crop at maturity. In a study of a traditional winter wheat cultivar, Maris Widgeon, and two modern cultivars, Hereward and Genesis, Cosser et al. (1997) found that sowing date affected weed impact and emergence more than cultivar. The traditional winter wheat cultivar tolerated weeds better than the newer cultivars. In low-input durum wheat (*Triticum durum* Desf.) systems, Barberi et al. (1999) suggested that mechanical methods alone would not always guarantee adequate weed control and grain yield.

Local flour mills want to receive spring wheat with protein content of 13.5% to meet their quality requirements. AC Barrie reached this goal in three of the four organic site-years (Fig. 1); however, AC Walton and Glenlea achieved 13.5% grain protein in only one of the four organic site-years. Although a pH of 5.7 at Springfield in 2000 was less than the recommended pH range of 6.0–7.0 for optimum cereal growth (Advisory Committee on Cereal, Protein, Corn and Forage Crops, 1991) and the potassium level was low, the added manure was high in N and K and growing conditions were good (Table 2), favoring AC Barrie more than AC Walton and Glenlea in yield and protein. At Springfield in 2001, all cultivars had less than 12% grain protein (Fig. 1). This low protein was attributed to the relatively low soil temperatures during the early part of the growing season (Table 3), resulting in slow mineralization of the applied manure and compost, and the extensive dry period during the growing season (Table 2), which reduced the uptake of available nitrogen.

In a survey of wheat crops in the UK, the protein content was consistently lower in organically produced samples compared to conventional samples (Starling and Richards, 1993). Similar results have been reported by others (Storey et al., 1993; Thompson et al., 1993). Therefore, in some years, spring wheat crops grown organically may have difficulty in achieving premium protein levels. A survey of literature (Taylor et al., 2001) indicated that quality specifications for markets of organic and conventional grain are similar, but standards for protein are more difficult to achieve in organic grain.

**Table 4. Analysis of variance for grain yield, test weight, kernel weight and percent protein for three spring wheat cultivars, and yield and protein for two soybean cultivars, in 2000 and 2001 at Springfield and Cherry Hill, Prince Edward Island.**

| | | Spring wheat[1] | | | | Soybean[2] | | |
|---|---|---|---|---|---|---|---|---|
| Source | df | Yield | Protein | Test weight | Kernel weight | df | Yield | Protein |
| Site (S) | 1 | 5.90** | 6.62** | 5.09 | 0.08 | 2 | 14.83** | 385.45** |
| Cultivar (C) | 2 | 0.75** | 5.65** | 246.09** | 363.04** | 1 | 0.07 | 17.52** |
| Weed treatment (W) | 1 | 0.03 | 0.06 | 0.36 | 4.35 | 1 | 0.01 | 0.07 |
| S × C | 2 | 0.87** | 2.03* | 18.43** | 25.55** | 2 | 0.14 | 26.08** |
| S × W | 1 | 0.00 | 0.03 | 0.22 | 3.71 | 2 | 0.01 | 1.73 |
| C × W | 2 | 0.01 | 0.12 | 0.14 | 0.27 | 1 | 0.02 | 0.27 |
| S × C × W | 2 | 0.02 | 0.26 | 0.60 | 0.51 | 2 | 0.01 | 1.68 |
| Residual | 36 | 0.07 | 0.41 | 1.84 | 1.58 | 47 | 0.06 | 1.69 |

[1]Both sites in both years.
[2]Cherry Hill site in 2000 and 2001 and Springfield site in 2001 only.
**Significant at $P < 0.01$.

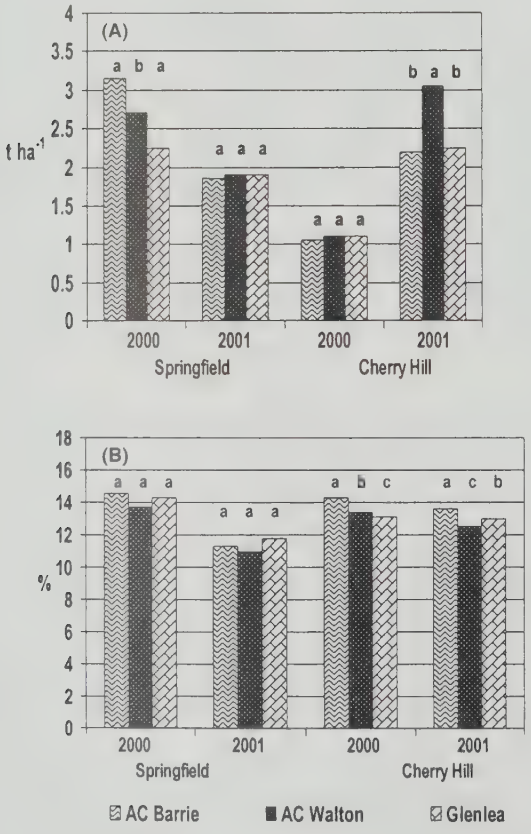


**Figure 1. Comparison of spring wheat grain yield (A) and protein (B) means of three spring wheat cultivars averaged over weed control treatments. Means within a year with the same letter are not significantly different at $P < 0.01$.**

**Table 5. Effect of weed control methods on number and dry weight of weeds[1] in spring wheat or soybeans.**

| | Total weed number[2] (number m$^{-2}$) | | Total dry weight (g m$^{-2}$) | |
|---|---|---|---|---|
| Site\Method | Wheat | Soybeans | Wheat | Soybean |
| 2000 | | | | |
| Cherry Hill | | | | |
| FL[3] + FW | 29 | 28 | 13 | 32 |
| FW[3] + FW | 33 | 26 | 10 | 45 |
| SE[4] | 1 | 3 | 1 | 8 |
| Springfield | | | | |
| FL + FW | 16 | not planted | 7 | not planted |
| FW + FW | 13 | | 10 | |
| SE | 2 | | 1 | |
| 2001 | | | | |
| Cherry Hill | | | | |
| FL + FW | 62 | 61 | 47 | 219 |
| FW + FW | 68 | 59 | 49 | 271 |
| SE | 13 | 9 | 7 | 29 |
| Springfield | | | | |
| FL + FW | 16 | 53 | 22 | 280 |
| FW + FW | 17 | 41 | 34 | 285 |
| SE | 3 | 8 | 6 | 49 |

[1]Predominant weeds at both sites were lamb's quarters, tufted vetch, plantain and hempnettle.
[2]Total weed count and dry weight data are from the date nearest harvest.
[3]FL, flaming; FW, fingerweeding.
[4]Cultivar-by-test interaction used to calculate standard error.

## Soybeans

Weed control treatments did not differ in effect on soybean cultivar yield and protein (Table 4). Soybean yield and protein differed between sites, and cultivars differed in percent protein (Fig. 2). In 2000, soybeans were grown at Cherry Hill only. Except for the effect of the drought in 2001 (Table 2), soybean yields were comparable to long-term yields of 1.8 t ha$^{-1}$, reported from conventional Maritime farms (Canada Grains Council, 2002). Küpper (2000) reported that in Arkansas, organic soybean yields are usually comparable to those obtained under conventional management. In 2001, protein content was approximately 5 percentage points greater at Cherry Hill than at Springfield for all cultivars (Fig. 2). Earlier seeding reduced

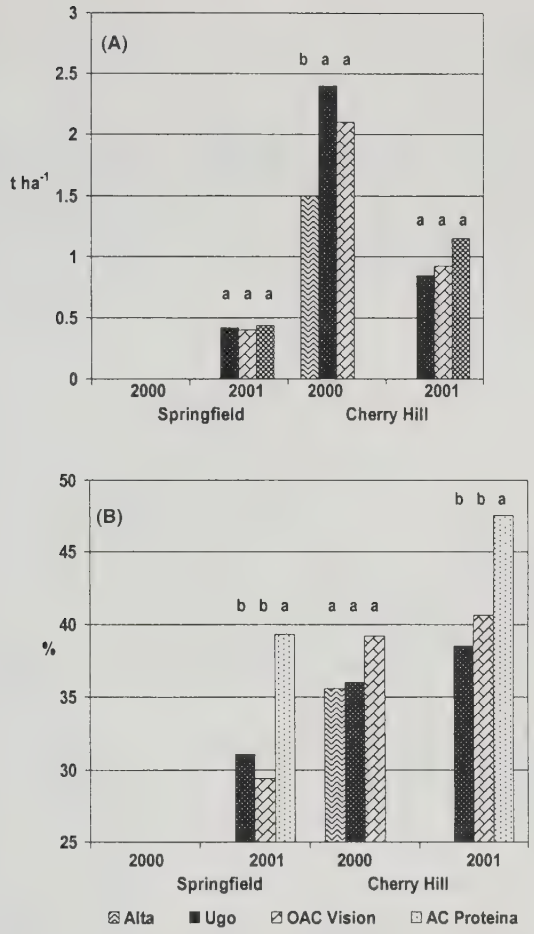


**Figure 2. Comparison of soybean yield (A) and protein (B) means of four soybean cultivars averaged over weed control treatments. Means within a year with the same letter are not significantly different at $P < 0.01$.**

the negative effect of the drought at Cherry Hill due to less moisture stress than at Springfield.

There was no difference between weed control methods on weed populations (Table 5). At Cherry Hill, the weed population and total dry weight in soybean were greater in 2001 compared to 2000 (Table 5). The predominant weeds were lamb's quarters (*Chenopodium album* L.), tufted vetch (*Vicia cracca* L.), broad-leafed plantain (*Plantago major* L.) and hempnettle (*Galeopsis tetrahit* L.). Our results were similar to the findings of Frick (1993) that specific weeds, such as lamb's quarters, increased in certain crops.

Spring wheat was a better competitor with weeds than soybean in this study (Table 5), for several reasons. Spring wheat grows faster than soybean early in the growing season and provides good competition to weeds through a greater biomass (Gruber et al., 2000). In this study, there was less competition to weeds from soybean plants than from spring wheat plants because the row spacing was twice as wide in soybean plots (Table 1) and soybean are slower to establish a canopy. Narrower row spacing may increase soybean competition against weeds because of an increased crop biomass with decreasing row width (Bullock et al., 1998).

## Conclusions

Spring wheat cultivars did not achieve 13.5% grain protein when soil moisture was limiting because mineralization of soil and manure did not provide sufficient nutrients to crops. The spring wheat cultivar AC Barrie may be especially suited to certain organic situations, as it outperformed AC Walton at Springfield in 2000 when growth conditions were favorable. Spring wheat yields were affected much less by the drought experienced in 2001 than soybean yields. There were no differences in weed control method between: (1) flaming followed by fingerweeding; and (2) fingerweeding twice, for all cultivars of both crops at two locations in 2 years.

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*Commentary*

# *USDA research on organic farming: Better late than never*

James F. Parr

As a former member of the 1979–80 USDA Study Team on Organic Farming, I read with keen interest the article by M.D. Jawson and C.T. Bull entitled 'USDA research into organic farming' published in the recent issue of the *American Journal of Alternative Agriculture* (17(4):201–202), although I was somewhat dismayed by its lack of relevancy and chronology of events which are essential to put this subject in proper perspective. The article heralds the current commitment that the US Department of Agriculture's Agricultural Research Service (USDA-ARS) is making to further organic farming research, and presents some notable results of this research effort, for which the agency, their cooperators, and consumers can be rightfully proud. Unfortunately, the article will likely leave most readers of *AJAA* with the impression that USDA has always been mindful and supportive of addressing the needs and problems of organic farming practitioners, which is simply not the case. Consequently, the purpose of this commentary is to improve our readers' understanding and perspective on the role of USDA-ARS in organic farming research in the US over the past 23 years. To do this requires that I cite and briefly discuss some highly relevant information that is lacking in Jawson and Bull (2002).

The involvement of USDA in organic farming *per se* began in 1979, when the then Secretary of Agriculture, the honorable Bob Bergland, appointed a team of USDA scientists to conduct a study on organic farming in the United States. The Secretary was well aware that conventional farming methods for cash grain production, based on intensive tillage and chemical inputs, were causing extensive environmental and economic problems. He was also very interested in whether organic farming systems could help to alleviate these problems, and, in directing the USDA Study Team on Organic Farming, he stated that: 'we need to gain a better understanding of these organic farming systems—the extent to which they are practiced in the United States, why they are being used, the technology behind them, and the economic and ecological impacts from their use. Moreover, we must identify the kinds of research and education programs that relate to organic farming' (USDA, 1980).

It is noteworthy that Secretary Bergland commissioned our team of USDA scientists to study organic farming systems because USDA was not conducting relevant research to address the needs and problems of organic farming practitioners; although, at that time, many insisted that the results of USDA's research on conventional farming systems could not help but benefit organic farming systems. Interestingly, Jawson and Bull (2002) make the same argument 23 years later when they state that 'over the years, organic farmers have closely followed the findings from USDA-ARS research on conventional farming systems'. This argument was soundly refuted by the USDA Study Team in their 1980 publication 'Report and Recommendations on Organic Farming' (USDA, 1980). The case studies of this report reflect a general agreement that research results from conventional farming systems did little to address the needs and problems of organic farmers. It's rather hard to believe that after 23 years, some still believe that organic farming is merely conventional farming without the use of chemical fertilizers and pesticides, truly a gross misconception. In their Report Summary, the USDA Study Team lists a number of research needs for organic farming, especially the need for a holistic or systems approach to focus on highly complex and poorly understood soil/plant chemical and microbiological interactions. An important finding of this report, and probably the best indication that USDA research was largely not applicable to organic farming systems, is that organic farmers, individually and through organic farming networks, were conducting *their own* on-farm research trials on aspects of crop rotations, nutrient cycling, organic waste management, pest biocontrol, tillage methods and alternative crops.

A very positive decision made by Secretary Bergland, and strongly recommended by the USDA Study Team, was to appoint a full-time Organic Farming Coordinator to foster and maintain lines of communication between USDA and the organic farming community (i.e., individual organic farmers, their networks and associations). Unfortunately, in January 1981, a new administration—not

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sympathetic to organic farming—took office. In 1982, the then Secretary of Agriculture, the honorable John R. Block, abolished the position of Organic Farming Coordinator because his administration did not consider organic farming research to be a sufficiently high priority. Obviously, this action quashed any hope of developing an effective and relevant USDA research program on organic farming systems recommended by the USDA Study Team in their 1980 report.

Meanwhile, the 1980 USDA publication 'Report and Recommendations on Organic Farming' rapidly became a 'bestseller'. Well over 100,000 copies were requested and distributed in the 1980s, and it was translated into at least five languages by the end of the decade. Probably the most important single factor that motivated US farmers to shift from conventional farming methods to organic farming was their concern for the adverse effects of pesticides on food safety and quality, human health and the environment (USDA, 1980). In due course, the American consumer movement began to express similar concerns about how US farmers might reduce their use of chemical fertilizers and pesticides as organic farmers were reportedly doing.

Finally, the US Congress, in its response to consumers' concerns and to counter USDA's then negative attitude toward organic farming, authorized USDA in 1985 to establish a research and education program on Low-input/ Sustainable Agriculture (LISA), which in 1990 became the Sustainable Agriculture Research and Education (SARE) program. While the missions of these programs were essentially the same, the creation of SARE reflected the deletion of the term 'low-input' which was highly objectionable to the American farm chemical industry. These programs were administered mainly through the USDA's Cooperative State Research Service (USDA-CSRS) with funds allocated to various state agricultural experiment stations and special grants programs. During this time there was little, if any, research on organic farming systems being conducted by USDA-ARS, except for a single scientist who had been assigned in 1984 to conduct cooperative research on organic farming at the Rodale Research Center.

The 1980 USDA Report generated considerable interest in the concept of 'alternative agriculture', which refers to the various alternative agricultural production practices and technologies that focus on minimal or non-use of chemical fertilizers and pesticides in US agriculture. This concept could help to enhance the development of long-term sustainable farming systems. The more general terms that have been used most widely during the past decade to designate such systems are 'alternative', 'sustainable', 'organic', and 'low-input'. Those seeking alternatives to conventional agriculture have tended to consider the term 'alternative' as one that encompasses the others (NRC, 1989). This overview was discussed by the National Research Council's Board on Agriculture in their report on 'Alternative Agriculture', published in 1989, which verified the findings and conclusions of the 1980 USDA's 'Report and Recommendations on Organic Farming' (NRC, 1989).

Two highly significant events occurred in 1993 with respect to the use of pesticides in US agriculture. First was a report by the National Research Council entitled 'Pesticides in the Diets of Infants and Children', released in June 1993, which indicated that these individuals could be at risk from ingestion of pesticide residues in food (NRC, 1993). Moreover, the report urged that tolerance levels for regulating permissible concentrations of pesticides and their residues in food be based primarily on health considerations rather than farming practices. Second was a joint statement released on June 25, 1993 by the Secretary of Agriculture (USDA), the Administrator of the US Environmental Protection Agency (USEPA) and the Commissioner of the US Food and Drug Administration (USFDA) that their agencies would henceforth work together and with US farmers to reduce pesticide use and to promote the principles of sustainable agriculture.

These two events did much to legitimize future research by USDA-ARS scientists on sustainable agriculture and related aspects of organic farming. But full authorization for USDA-ARS scientists to conduct research on organic farming systems *per se* didn't come until 1998, with passage of an Organic Farming Bill by the US Congress. Consequently, the USDA-ARS research results on organic farming cited by Jawson and Bull (2002) from the article 'Organic grows on America' (Wood et al., 2002) are based on relatively recent initiatives. Thus, in this regard, many of us can't help but say 'good show and better late than never', despite the fact that the road to organic farming research in the US has had so many obstacles and detours.

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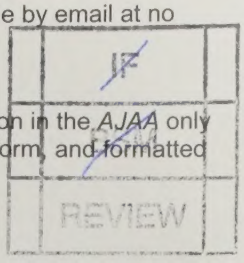

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